CONSULTANT REPORT

REGIONAL TRANSMISSION AND DISTRIBUTION NETWORK IMPACTS ASSESSMENT FOR WHOLESALE PHOTOVOLTAIC GENERATION

Prepared for: California Energy Commission

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PREFACE

New Power Technologies, as a subcontractor to Aspen Environmental Group, performed this study for the California Energy Commission under Work Authorization WA1930.007 under Contract 1930-07 between the Energy Commission and Aspen Environmental Group.

DISCLAIMER

Any results, findings, or conclusions included in this report relating to specific photovoltaic generation project interconnections should be viewed as illustrative. This study is intended to evaluate an approach to determine if it is feasible with available data and whether it can provide a new level of visibility that is useful for assessing regional impacts of photovoltaic generation at high penetrations relative to load. This study is not intended to provide conclusive interconnection results for the specific photovoltaic generation projects in question or to formally replace Pacific Gas and Electric Company's interconnection request review process. The interconnection points for the photovoltaic generation projects discussed herein have not been confirmed by Pacific Gas and Electric Company personnel. Consistent with the approved scope at this interim stage, New Power Technologies has not completed the full software integration of the subject study area source data, so the simulation model should not be viewed as fully checked or final.

ABSTRACT

The Integrated Transmission and Distribution Model for Assessment of Distributed Wholesale Photovoltaic Generation demonstrates the use of a high-definition regional power system simulation model, with both transmission and distribution systems featured, to evaluate the individual, group, and area grid impacts of large exporting wholesale photovoltaic interconnections that would exceed locally served load. The study provides a system-level view using actual utility data versus representative approximations. It also allows representation of individual generation projects at the actual point of interconnection in either distribution or transmission with full characterization of power network features.

The study incorporates 122 interconnection requests for 1.5 megawatt to 100 megawatt projects in a modeled network serving roughly 390 megawatts (peak) of load, including 51 distribution feeders, and supporting substations and regional transmission over an area of about 3,500 square miles. The study provides a method for systematic evaluation of individual, group, and regional impacts of wholesale photovoltaic interconnections.

Study results indicate that all interconnections are different, and that generalizations and approximations may obscure results. Wholesale photovoltaic in distribution can affect substations and regional transmission, and nominally transmission and distribution interconnections can affect the same network infrastructure. Studying the interconnections of a region together in one model shows that projects under different interconnection processes and in different utility planning areas may have mutual or group impacts. Representing many generation projects, distribution feeders, substations, and transmission in a single model makes it easier to evaluate alternative interconnection schemes and better understand reverse power flow in order to reduce impacts from load fluctuation.

Keywords: Distributed generation, interconnection, high penetration, low impact, photovoltaic, renewable, impact, wholesale, export, grid, power delivery, system, distribution, transmission, Renewables Portfolio Standard

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EXECUTIVE SUMMARY

A portion of California's ambitious renewable power generation goals will be met with wholesale photovoltaic generation projects, which are intended to export power to the grid under a purchase agreement rather than serve local load, such as a residential rooftop net energy metering project. Such projects may be connected to the power grid at points within distribution feeders, which are typically the distribution system lines delivering electricity to customers. Distribution feeders were originally designed to serve customers loads; they also may be connected at substations or at points in the transmission system. Further, developers often prefer to site wholesale photovoltaic projects in rural locations with light electrical loads. Thus, within a region, these wholesale photovoltaic projects may affect the power grid at more than their point of interconnection or within the individual distribution feeder; the influence of these projects may extend through a substation to the transmission system, and the impacts may compound to affect an entire regional power delivery network.

When distributed generation projects are evaluated for interconnection with the power grid, the process generally considers the impacts of individual projects or, in some cases, clusters of projects within the distribution system. Where the output of distributed generation projects remains much smaller than locally served load, the operation of the power network may be only modestly affected. Little formal inquiry on how multiple distribution-connected generation projects intended to export power and whose output exceeds locally served load may affect the regional transmission grid. More importantly, the behavior and influence of distribution feeder-connected generation projects beyond the feeder, in the substation and on the transmission level, are not well-represented in a traditional study approach that decouples transmission and distribution analysis.

In addition to the foregoing, the cost and time involved in the generator interconnection process, including specifically the ability to consider different project configurations and how projects may be grouped in clusters for evaluation, continue as concerns among developers and network operators in California.

This study considers a region in California where there is significant developer interest in wholesale photovoltaic (PV) generation projects and proposed interconnections exceed local load, and evaluates the individual, group, and regional grid impacts of these projects using a tool that integrates the distribution feeders, substations, and transmission of a region in a single simulation model. This approach provides several advantages over a traditional approach that decouples individual distribution feeders and transmission:

- Projects are represented as and where they would be interconnected—at specific nodes within distribution feeders, at substations or in the transmission system—and with the attributes and features of the network in detail.

- The impacts of distribution-connected projects on transmission and the impacts of transmission-connected projects on distribution are directly visible.
- The proposed wholesale photovoltaic projects of a region, whether nominally distribution- or transmission-connected, are represented together in one model, so any mutual or compounding impacts on the grid are directly visible.
- There is no need for equivalently representing distribution feeder-connected projects at substation or transmission network nodes, reducing portions of the power network, relying on representative feeders in place of individually modeled feeders, or using rules of thumb, all of which could obscure important results.
- The model provides ready access to additional network assets, such as neighboring feeders or substations, that are near a given wholesale PV project, either geographically or within the network topology, or utility system configuration, making it easy to identify and evaluate alternative project interconnection schemes.

These results, and the use of a high-definition, regionwide, integrated transmission and distribution model to asses a diverse set of wholesale photovoltaic projects, show the following:

- Distribution-connected wholesale photovoltaic projects can affect regional transmission, in groups and in, some cases, individually.
- Transmission-connected wholesale photovoltaic projects can affect distribution.
- Each project interconnection is different. It is difficult to generalize about the grid impacts of projects of a given size, and approximations may obscure important findings.
- Projects with mutual or group impacts may not be related institutionally (for example, proposed under distinct distribution or transmission interconnection processes) or geographically (for example, within a given utility distribution planning area). In fact, given a mix of proposed distribution and transmission project interconnections, some simulation analysis in the integrated regional model is needed to determine those projects that have mutual impacts or that affect common infrastructure.

The approach of this study includes simulations and impact assessments of each of the wholesale photovoltaic interconnections considered. These results thus offer findings that relate to the larger challenge of accommodating wholesale photovoltaic projects in the power delivery network to support California's renewable power generation goals:

- Identifying and avoiding weak network interconnections may significantly reduce the impacts of variable-output photovoltaic generation on the power delivery network. A simple voltage impact ratio may be a useful way to identify such weak interconnections.

- It is more common for wholesale photovoltaic project output to exceed thermal power flow ratings than to cause voltage violations (particularly if weak interconnection alternatives are avoided). Local loads offset these flows, suggesting active management of wholesale output under light load conditions as a way to reduce wholesale photovoltaic impacts and increase the ability of the power delivery system to accommodate wholesale photovoltaic.
- Greater networking of existing radial transmission systems, which have only one source of power delivered to the subtransmission level, may increase the ability of the power delivery system to accommodate wholesale photovoltaic.

Finally, this study offers a method for systematically evaluating the individual, group, and regional impacts of grid interconnections of large amounts of wholesale photovoltaic.

The distribution system considered for this study, in the greater Fresno area, was identified by Pacific Gas and Electric Company in light of the wholesale photovoltaic developer interest and pending project interconnection requests. Overall, this study incorporates 122 generation project interconnection requests, including a mix of nominal distribution and transmission interconnections, ranging from 1.5 megawatts to 100 megawatts, in a modeled network serving about 390 megawatts (peak) of load. The modeled network includes 51 distribution feeders, supporting substations, and regional transmission over an area of roughly 3,500 square miles, and the western United States transmission grid. Pacific Gas and Electric Company also provided the distribution feeder and substation data from which New Power Technologies developed the distribution portion of the integrated system model. Accordingly, no wholesale photovoltaic projects that would connect to the grid in Southern California Edison Company's or San Diego Gas & Electric Company's service territories were evaluated.

The study region might be termed an area of potential high penetration of photovoltaic generation—that is, where local photovoltaic generation is significant relative to local load. In fact, in this study potential local photovoltaic generation greatly exceeds local load, and power export from feeders and reversal of prevailing power flows are common. Moreover, local photovoltaic generation as a share of local load as a stand-alone descriptor is not particularly indicative of the nature or extent of the grid impacts of these projects.

These results provide numerous specific examples where large amounts of incremental wholesale generation can be incorporated in a power system without overloading lines or causing voltage violations, and where the impact of any generation project output variability lies well within the control capability of the power systems. In the end, this suggests that high penetration or the variable output of wholesale photovoltaic generation isn't a general concerns, even though projects proposed for specific network locations may well have real issues. Most importantly, such issues can be identified when and where they arise for potential mitigation or avoidance.

CHAPTER 1: Introduction

Problem Statement

The State of California has established an ambitious renewable power generation goal, a portion of which will be met with wholesale or exporting photovoltaic (PV) generation projects. As an example, **Figure 1** shows the Aleatico Park development, a very significant wholesale PV generation project now in operation and discussed in this report. The colored lines in the background are Aleatico and Kadarka distribution feeders and the 70 kilovolt (kV) transmission line serving Aleatico substation.

Figure 1: Aleatico Park Photovoltaic Project

Source: New Power Technologies.

Wholesale generation projects are intended to export power to the grid rather than serve on-site electrical load. Nonetheless, these projects are, in many cases, connected to the power delivery network at points in the distribution system, a system nominally intended to deliver power from the bulk electric power system to customer loads. Furthermore, wholesale PV developers may prefer rural sites, where the existing electrical loads within the distribution system are also light. As a result, there is the possibility that wholesale generation projects may have cumulative effects on the regional transmission grid and local impacts within the local distribution network.

The process under which these projects are connected to the power delivery network (either in distribution or transmission) generally considers the impacts of individual projects or, in some cases, clusters of projects within the network. However, there has been little formal inquiry into how distribution feeder-connected generation projects may affect the regional transmission grid. Present feeder-level distribution analysis tools are unwieldy for evaluating many distribution-connected generation projects over a large number of distribution feeders in a power delivery region in a single analysis.

At the same time, the behavior and influence of distribution feeder-connected generation projects on transmission are not well-represented in regional transmission-only models. Likewise, any interplay between generation projects to be connected to the transmission system and distribution feeder-connected projects is not directly visible in a transmission-only model. The present use of distinct distribution analysis tools and transmission analysis tools effectively decouples (or treats as separate) the transmission and distribution portions of the power delivery network; such tools are not readily suited to evaluate impacts that may extend from distribution to transmission and vice-versa. Thus, there is a need for studies and tools that capture the detail of distribution and distribution feeder-connected generation along with transmission (and transmission-connected generation) for a unified regional view.

The processes through which wholesale generation projects are connected to the grid are also affected by institutional boundaries. In California the transmission grid is under the management of the California Independent System Operator (California ISO), while the distribution systems are under the management of load-serving entities (utilities). Depending on the characteristics, wholesale generation projects may be evaluated for interconnection by any of these entities. Ways to reduce the time and cost of these processes and improve their outcomes are topics of ongoing discussions among stakeholders. However, for this study, a more consequential observation is there is not a formal process to determine how the effects of projects under review by different entities may compound each other.

Contract 1930-07 between the California Energy Commission and Aspen Environmental Group included technical support and training for electricity supply analysis, including, specifically, electricity system and infrastructure analysis (Task 2). Accordingly, the objectives of Work Authorization 1930.007 under Contract 1030-07 were to:

- Develop models and datasets that represent the local and regional impacts of distribution-connected wholesale generation in a particular region of California's transmission system.

- Demonstrate the use of tools that capture the detail of distribution and distribution-connected generation in a regional or transmission-level view.
- Provide data sets and related tools and assistance to allow Energy Commission staff to analyze regional and transmission impacts of distribution-connected generation.

Under the work authorization, New Power Technologies would implement NPT's Energynet® platform and power system simulation as a systemwide model having distribution element-level detail.[1] This model can show the network impacts of distribution-level measures—including distribution-connected power generation—within the feeder at the level of individual distribution devices as well as wide-area impacts of multiple projects. The subject area of the regional delivery network for this simulation is a portion of the Pacific Gas and Electric Company (PG&E) system in which interconnection requests for wholesale generation exceed local load; accordingly, it is likely that the impact of these wholesale generation projects, if built, would be visible within the regional transmission system as well as within the distribution circuits.

The contractor's goals under the work authorization were to:

- Establish an analytical tool that depicts the following in an integrated transmission and distribution model:
    - Local, subcircuit impacts of individual wholesale PV generation units.
    - Circuit-level controls such as voltage regulation and stepdown transformer taps.
    - Regional transmission.
- Perform certain analyses relating to local and regional impacts of proposed distributed wholesale generation projects in the study area.
- Provide data sets for the use of Energy Commission staff.
- Provide guidance to Energy Commission staff for other analyses.

Project Objectives

The objectives of the project included the following:

- Develop integrated regional transmission and distribution model of the study area.

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1 The Energynet approach was initially demonstrated by New Power Technologies under Public Interest Energy Research (PIER) Contracts #500-01-039 and #500-04-008.

- Model the set of queued projects proposed for interconnection in the study area as an example of high penetration of distributed generation, and make this dataset available for Energy Commission staff use.
- Evaluate the potential impacts of queued projects proposed for interconnection.

How these objectives were accomplished is discussed in Chapter 2, Approach, and the outcomes are discussed in Chapter 3.

For this WA, New Power Technologies would use data provided to New Power Technologies by PG&E under a nondisclosure agreement. The deliverables under the WA disguise PG&E customer information and PG&E proprietary information, consistent with the nondisclosure agreement. Accordingly, the PG&E substation names used in this report are aliases, and the identifiers for wholesale PV projects are substituted.

Innovations

The approach of this project departs from conventional practice in the evaluation of distribution-connected wholesale and transmission-connected wholesale generation together, using a simulation incorporating both distribution and transmission portions of the subject power delivery network. In addition, this single integrated simulation includes many or all of the distribution feeders of the subject power delivery network.

Under this approach a single analysis can illuminate project impacts at the point of interconnection, within any distribution feeder, within the family of circuits served from the source substation, and within the local and regional transmission. This approach also provides conclusions based on simulation results rather than relying solely on rules of thumb. These results demonstrate these outcomes.

Incorporating a particular wholesale generation project in such a model is straightforward, no matter how or where it is proposed for connection. Evaluation of such alternatives is facilitated by a simulation tool with many distribution feeders and the related substations and upstream transmission infrastructure directly at hand.

Most importantly, the study approach does not require the use of equivalized, or of equal size and value, representation of feeder-connected projects at substation buses, or reduced feeder models, or rely on the use of representative feeder models. These results show clearly that the impact of a given project on the network depends highly upon the network characteristics at the point of interconnection of the project. These results also show that outlier interconnections—in terms of projects, network conditions, or the combination—can have behavior that might affect practice and policy; thus drawing general conclusions without an evaluation that would reveal such outliers comes with great risk.

CHAPTER 2: Approach

Study Area

For this project, New Power Technologies refers to the study area as the Vineyard system. The study area for this project was based on specific substations and the associated five PG&E distribution planning areas (DPAs):

- DPA incorporating Aleatico Substation (Kadarka DPA)
- DPA incorporating Tibouren Substation (Bonarda DPA)
- DPA incorporating Grasa Substation (Gamay DPA)
- DPA incorporating Sangiovese Substation (Madrasa DPA)
- DPA incorporating Cereza Substation (Lumassina DPA)

These substations and the associated DPAs have active developer interest for development of wholesale generation projects as evidenced by requests to interconnect under PG&E's wholesale distribution access tariff (WDAT). This portion of PG&E's distribution system also serves relatively light existing network load. Thus, this area offers a real-world example of high penetration of wholesale generation with generation approaching or exceeding locally served load.

Each of these PG&E DPAs typically includes four substations, each of which typically serves 2-3 distribution feeders or circuits. Thus, this set of DPAs includes the distribution feeders listed in **Table 1**.

Table 1: Distribution Feeders in Study Area

DPA	Substation	Feeder	Nominal Voltage (kV)
Kadarka	Aleatico	Aleatico 2101	21
Kadarka	Dolcetto	Dolcetto 1101	12
Kadarka	Dolcetto	Dolcetto 1102	12
Kadarka	Kadarka	Kadarka 1101	12
Kadarka	Kadarka	Kadarka 2104	21
Kadarka	Trepat	Trepat 1104	12
Kadarka	Trepat	Trepat 1106	12
Kadarka	Trepat	Trepat 2108	21
Bonarda	Aragonez	Aragonez 1101	12
Bonarda	Aragonez	Aragonez 1102	12
Bonarda	Charbono	Charbono 1102	12
Bonarda	Charbono	Charbono 1103	12
Bonarda	Bonarda	Bonarda 1102	12
Bonarda	Bonarda	Bonarda 2101	21
Bonarda	Tibouren	Tibouren 1102	12
Bonarda	Tibouren	Tibouren 2105	21
Gamay	Gamay	Gamay 1101	12
Gamay	Gamay	Gamay 1102	12
Gamay	Gamay	Gamay 1104	12
Gamay	Gamay	Gamay 1105	12
Gamay	Grasa	Grasa 1102	12
Gamay	Grasa	Grasa 1103	12
Gamay	Cortese	Cortese 1101	12
Gamay	Cortese	Cortese 1102	12
Gamay	Cortese	Cortese 1103	12
Gamay	Cortese	Cortese 1104	12
Lumassina	Lumassina	Lumassina 1101	12
Lumassina	Lumassina	Lumassina 1102	12
Lumassina	Lumassina	Lumassina 1103	12
Lumassina	Lumassina	Lumassina 1104	12
Lumassina	Lumassina	Lumassina 1105	12
Lumassina	Cereza	Cereza 1102	12
Lumassina	Cereza	Cereza 1103	12
Lumassina	Cereza	Cereza 1104	12
Lumassina	Cereza	Cereza 1105	12
Lumassina	Helfensteiner	Helfensteiner 1101	12
Lumassina	Helfensteiner	Helfensteiner 1102	12
Madrasa	Sangiovese	Sangiovese 1101	12
Madrasa	Sangiovese	Sangiovese 1102	12
Madrasa	Sangiovese	Sangiovese 1104	12
Madrasa	Madrasa	Madrasa 1104	12
Madrasa	Madrasa	Madrasa 1105	12
Madrasa	Madrasa	Madrasa 1106	12
Madrasa	Barbera	Barbera 1101	12
Madrasa	Barbera	Barbera 1102	12
Madrasa	Barbera	Barbera 1103	12
Madrasa	Barbera	Barbera 1104	12
Madrasa	Canaiolo	Canaiolo 1101	12
Madrasa	Canaiolo	Canaiolo 1102	12
Madrasa	Canaiolo	Canaiolo 1104	12
Madrasa	Canaiolo	Canaiolo 1105	12

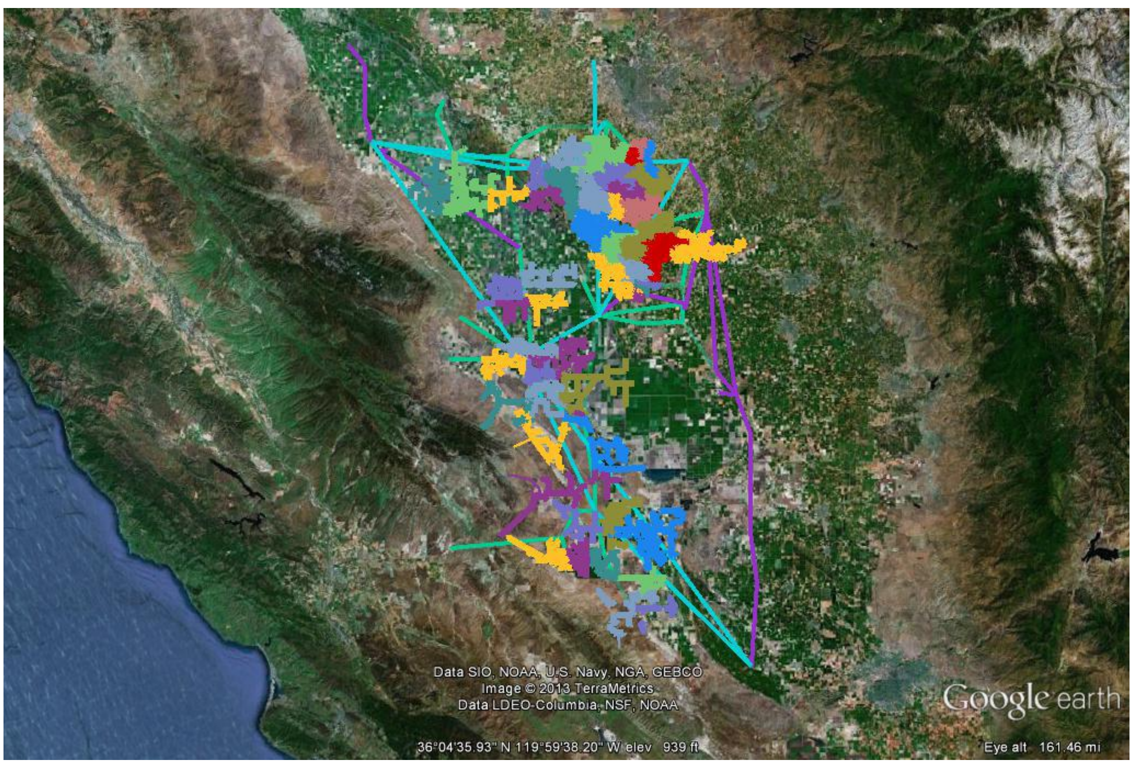
Source: New Power Technologies.

Consistent with an integrated transmission and distribution model, the study area also includes the regional transmission network serving these DPAs, which in this case includes 70 kilovolts (kV), 115 kV, and 230 kV regional transmission, as well as 500 kV transmission and the westwide transmission network.

During the study, the scope expanded to include consideration of those projects requesting interconnection directly with the regional transmission grid that also might be electrically related to the power delivery network represented by these five PG&E DPAs and the previously noted WDAT interconnection requests.

The resulting study area is shown in **Figure 2**. The colored zones are the line segments of each of the distribution feeders listed above. The regional transmission lines shown in **Figure 2** are represented as straight lines, in dark turquoise (230 kV), purple (115 kV), and turquoise (70 kV). (For clarity, the regional 500 kV transmission incorporated in the study area and model is not shown.)

Figure 2: Study Area



Source: New Power Technologies.

The **Figure 2** study area is defined to capture regions and substations within PG&E's distribution system with intense developer/interconnection interest, rather than an attempt to include all distribution infrastructure served from the regional transmission.

The resulting Vineyard study area spans a geographic area of roughly 3,500 square miles. The portion of the network that is modeled down to distribution serves about 390 megawatts (MW) (peak) of end-use customer load. Within this study area, New Power Technologies incorporated 122 distribution or transmission interconnection requests representing nearly 5,600 MW. As explained below, these include granted, pending, and withdrawn requests. Acknowledging that only a fraction will actually be built, this is clearly an area where potential wholesale PV development far exceeds locally served load.

Energynet Platform

For this project New Power Technologies developed an Energynet power system simulation for the Vineyard system. The Energynet simulation incorporates a power system model and simulation of the entire lines network of a regional power delivery system, incorporating regional transmission, local transmission, and distribution. The simulation includes all distribution substations, circuits, and components. The model includes a representation of the relevant system element details, including individual line segment conductor ratings and configuration within every distribution feeder, the presence and location of voltage control devices, and the proximity of existing distributed generation. The simulation can provide voltage and real and reactive power flow conditions at any point in the system under an actual system arrangement or under any hypothetical condition, such as with the addition of wholesale PV projects. The simulation can represent conditions as a static snapshot or in a series of snapshots reflecting lack of steady-state or quasidynamic behavior

The Energynet platform is thus well-suited to reveal the impacts of wholesale PV projects connected at points in the distribution network on voltage and power flow at the point of interconnection of each project, within the interconnecting circuit, on adjacent circuits and substations, and on the local and regional transmission system. The Energynet model is generated with software using typical legacy system data and can be updated as often as the underlying source data are updated.

To support this project, PG&E provided data extracted from legacy data systems characterizing the distribution feeders within the study area, as well as single line drawings for the relevant substations. All data sources were provided from the source systems as-is, without any special handling or preprocessing for this project. The distribution feeder data characterize that portion of the system as of April 2012.

For the regional transmission system characterization, Energy Commission staff provided Western Electricity Coordinating Council (WECC) data sets characterizing regional and westwide of the greater Southern Central California area of transmission for the summer of

2012 under light summer load[2] and heavy summer load[3] conditions. New Power Technologies assumed, but did not confirm, that both cases represent the same assets, with the differences between the data sets in the loads and dispatch of resources only. For this study, New Power Technologies used the light summer load case as the basis for a minimum daytime load scenario, and minimum daytime load conditions when used here in reference to the transmission system mean this light summer load case.

Distribution Loads

Reasonable characterization of the distribution portion of an Energynet integrated power system model requires customer-level or service transformer-level loads. New Power Technologies has demonstrated validated power system models without the need for loads measured at customer locations (for example, load data from automated metering infrastructure).[4][5] For this project New Power Technologies estimated distribution loads for peak conditions from feeder peak loads included in the circuit data provided by PG&E. New Power Technologies found that the peak loads given for individual feeders were generally consistent with the substation loads identified in the heavy-load regional transmission case.

In the absence of hourly circuit or substation load data that could be used to directly determine minimum daytime loads, New Power Technologies estimated minimum daytime loads as 35 percent of peak loads. This relationship of peak loads to minimum daytime loads is supported by evaluations of actual hourly load data for other California power delivery systems.[6][7]

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2 WECC "12ls1a" case.

3 WECC "12hs4a" case.

4 Evans, P., et al, "Validation of high-definition electric power delivery network simulation," IEEE Power and Energy Society General Meeting, 2010; PESGM 2010. IEEE 25-29 August 2010.

5 New Power Technologies, *Verification of Energynet Methodology*, California Energy Commission, CEC-500-2010-021, December 2010.

6 New Power Technologies, *Identification of Low-Impact Interconnection Sites for Wholesale Distributed Photovoltaic Generation using Energynet Power System Simulation*, CEC-200-2011-014, December 2011.

7 New Power Technologies, "MW-Class Distribution-Connected PV: Area-Level Identification of Low Impact Sites," presentation to California Public Utilities Commission Renewable Distributed Energy Coalition (ReDEC), March 2011.

Wholesale Photovoltaic Projects

The study area is a region of active developer interest for photovoltaic generation projects, with an emphasis on photovoltaic generation. Based on a review of the WDAT queue[8], the relevant projects for the study area DPAs are listed in **Table 2**. For this work authorization, New Power Technologies included in the model projects shown as withdrawn in the WDAT queue, as well as projects still pending. The withdrawn projects may provide additional examples for evaluating the analytical approach of this study should the reasoning for the withdrawal be known.

New Power Technologies also reviewed the California ISO Controlled Grid Generation Queue[9] for projects that might lie in or affect the regional power delivery system in the project study area. The California ISO queue includes more than 200 projects[10] identified as connecting to the PG&E network and located within Fresno, Kern, or Kings Counties. In many cases the interconnection point of the project is identified only as a long-distance transmission line spanning several substations, so it is difficult to tell if a project would directly affect one of the regional transmission substations serving the DPAs that are the focus of this study. **Table 3** and **Table 4** list the California ISO queue projects that New Power Technologies assessed as clearly connected at or affecting one of the substations directly serving the study area DPAs. Again, for this project New Power Technologies included in the model projects shown as withdrawn in the California ISO queue.

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8 PG&E's published queue of generator interconnection requests under its WDAT, dated as of March 27, 2012.

9 California ISO Controlled Grid Generation Queue, report run August 31, 2012.

10 Including both active and withdrawn projects.

Table 2: Queued WDAT Interconnection Requests

ID	Substation	Interconnecting Bus	Bus Number	Rated Output (kW)	Type
W1	Aleatico	SLR6	34619	20,000	PV
W2	Aleatico	SLR9	34623	10,000	PV
W3	Aleatico	SLR3	34617	19,000	PV
W4	Aleatico	Bus_S2550021000_21kV_OperatingBus	500500	20,000	PV
W5	Aleatico	Aleatico Sub 70 kV bus	34546	50,000	PV
W5 (alt)	Aleatico	Bus_F255002101_ND1200174338	700396	50,000	PV
W6	Aleatico	Bus_S2550021000_21kV_OperatingBus	500500	20,000	PV
W6 (split)	Aleatico	Bus_F255002101_ND1200066879	700254	10,000	PV
W6 (split)	Kadarka	Bus_F252732104_ND1200034955	700955	10,000	PV
W6 (split)	Kadarka	Bus_F252732104_ND1200180798	701135	10,000	PV
W7	Kadarka	Bus_F252731101_swt_21	700617	3,000	PV
W8	Kadarka	Bus_F252731101_ND1200027614	700660	3,000	PV
W9	Trepat	Bus_F252951106_swt_6	702517	20,000	PV
W9 (alt)	Trepat	Bus_S2529512000_12kV_MainBus_D	500505	20,000	PV
W10	Trepat	Bus_F252951106_ND1200027768	702596	20,000	PV
W10 (alt)	Trepat	Bus_S2529512000_12kV_MainBus_E	500507	20,000	PV
W11	Dolcetto	Bus_S234512000_12kV_MainBus	500503	20,000	PV
W12	Dolcetto	Bus_S234512000_12kV_MainBus	500503	20,000	PV
W13	Bonarda	Bus_S2546812000_12kV_MainBus_D	500513	12,000	PV
W14	Bonarda	Bus_F254682101_ND1300248905	706073	12,000	PV
W15	Tibouren	Bus_S2544012000_12kV_MainBus_D	500515	20,000	PV
W16	Tibouren	Bus_F254402105_swt_10	707008	1,500	PV
W17	Tibouren	Bus_S2544012000_12kV_MainBus_D	500515	15,000	PV
W18	Tibouren	Bus_S2544012000_12kV_MainBus_E	500516	15,000	PV
W19	Tibouren	Bus_F254402105_ND1300019674	707139	3,000	PV
W20	Tibouren	Bus_F254402105_ND1300019674	707139	3,000	PV
W21	Aragonez	Bus_S2520212000_12kV_MainBus	500509	10,500	PV
W22	Bonarda	Bus_F254681102_ND1300042518	705602	10,080	PV
W23	Dolcetto	Bus_F253451102_ND1300010673	701877	1,500	PV
W24	Gamay	Bus_S2539312000_12kV_MainBus_D	500518	20,000	PV
W25	Gamay	Bus_S2539312000_12kV_MainBus_G	500521	10,000	PV
W25 (alt)	Gamay	Bus_F253931105_struc_43	709686	10,000	PV
W26	Gamay	Bus_S2539312000_12kV_MainBus_G	500521	5,000	PV
W26 (alt)	Gamay	Bus_F253931105_swt_24	709625	5,000	PV
W27	Gamay	Bus_S2539312000_12kV_MainBus_G	500521	5,000	PV
W27 (alt)	Gamay	Bus_F253931101_ND1200044489	707607	5,000	PV
W27 (alt)	Gamay	Bus_F253931105_struc_65	709698	5,000	PV
W28	Gamay	Bus_F253931101_ND1200044489	707607	2,000	PV
W29	Grasa	Bus_S2531512000_12kV_MainBus_D	500525	20,000	PV
W29 (alt)	Grasa	Bus_F253151103_struc_285	710618	20,000	PV
W29 (alt)	Grasa	Bus_F253151103_struc_285	710618	8,200	PV
W30	Grasa	Bus_S2531512000_12kV_MainBus_D	500525	12,000	PV
W30 (alt)	Grasa	Bus_F253151103_struc_126	710529	12,000	PV
W31	Grasa	Bus_S2531512000_12kV_MainBus_D	500525	10,000	PV
W31 (alt)	Grasa	Bus_F253151102_struc_149	710144	10,000	PV
W32	Grasa	Bus_S2531512000_12kV_MainBus_D	500525	10,000	PV
W32 (alt)	Grasa	Bus_F253151102_struc_149	710144	10,000	PV
W33	Grasa	Bus_S2531512000_12kV_MainBus_D	500525	1,500	PV
W34	Gamay	Bus_S2539312000_12kV_MainBus_G	500521	20,000	PV
W35	Cereza	Bus_F252301102_struc_1401	716007	1,500	PV
W36	Cereza	Bus_F252301104_struc_1279	718721	1,500	PV
W37	Cereza	Bus_F252301104_struc_1279	718721	1,500	PV
W38	Cereza	Bus_F252301104_struc_1279	718721	1,500	PV
W39	Cereza	Bus_F252301104_struc_1279	718721	1,500	PV
W40	Helfensteiner	Bus_F253711101_struc_838	721081	925	Recip
W41	Cereza	Bus_F252301104_fus_93	718233	1,500	PV
W42	Sangiovese	Bus_F253661101_cap_1	724018	1,450	PV
W43	Sangiovese	Bus_F253661101_struc_29	724076	20,000	PV
W43 (alt)	Sangiovese	Bus_S2536612000_12kV_MainBus_D	500540	20,000	PV
W44	Sangiovese	Bus_F253661101_struc_77	724062	20,000	PV
W44 (alt)	Sangiovese	Bus_S2536612000_12kV_MainBus_D	500540	20,000	PV
W45	Sangiovese	Bus_F253661101_cap_1	724018	1,450	PV
W46	Sangiovese	Bus_S2536612000_12kV_MainBus_D	500540	20,000	PV

Source: New Power Technologies.

Table 3: Queued California ISO Interconnection Requests

ID	Substation	Interconnecting Bus	Bus Number	Rated Output (kW)	Type
I1	Gamay	Gamay Sub 230 kV bus	30900	110,000	PV
I2	Gamay	Gamay Sub 230 kV bus	30900	500,000	PV
I3	Gamay	Gamay Sub 500 kV bus	30055	800,000	PV
I4	Gamay	Gamay Sub 230 kV bus	30900	106,800	ST
I5	Gamay	Gamay Sub 230 kV bus	30900	-	CC
I6	Gamay	Gamay Sub 230 kV bus	30900	106,800	ST
I7	Gamay	Gamay Sub 230 kV bus	30900	600,000	CC
I8	Gamay	Gamay Sub 500 kV bus	30055	250,000	PV
I9	Grasa	Grasa Sub 70 kV bus	34470	20,000	PV
I10	Grasa	Grasa Sub 70 kV bus	34470	17,900	PV
I11	Helfensteiner	Helfensteiner Sub 70 kV bus	34458	13,400	PV
I12	Cereza	Cereza Sub 70 kV bus	34508	14,000	PV
I13	Hondarribi	Hondarribi Sub 70 kV Bus	34540	12,000	PV
I14	Hondarribi	Hondarribi Sub 70 kV Bus	34540	7,800	PV
I15	Abbouto	Abbouto Switch	34554	5,000	PV
I16	Hondarribi	Hondarribi Sub 70 kV Bus	34540	20,000	PV
I17	Hondarribi	Hondarribi Sub 70 kV Bus	34540	19,200	PV
I18	Hondarribi	Hondarribi Sub 70 kV Bus	34540	-	CT
I19	Hondarribi	Hondarribi Sub 70 kV Bus	34540	150,000	ST
I20	Hondarribi	Hondarribi Sub 70 kV Bus	34540	15,000	PV
I21	Hondarribi	Hondarribi Sub 70 kV Bus	34540	20,000	PV
I22	Hondarribi	Hondarribi Sub 70 kV Bus	34540	17,750	PV
I23	Hondarribi	Hondarribi Sub 70 kV Bus	34540	20,000	PV
I24	Hondarribi	Hondarribi Sub 70 kV Bus	34540	20,000	PV
I25	Hondarribi	Hondarribi Sub 70 kV Bus	34540	20,000	PV
I26	Hondarribi	Hondarribi Sub 70 kV Bus	34540	10,000	PV
I27	Joubertin	Joubertin Sub 70 kV bus	34542	20,000	PV
I28	Joubertin	Joubertin Sub 70 kV bus	34542	13,500	PV
I29	Joubertin	Joubertin Sub 70 kV bus	34542	20,000	PV
I30	Joubertin	Joubertin Sub 70 kV bus	34542	20,000	PV
I31	Joubertin	Joubertin Sub 70 kV bus	34542	20,000	PV
I32	Hondarribi	Hondarribi Sub 115 kV Bus	34430	49,000	Other
I33	Hondarribi	Hondarribi Sub 115 kV Bus	34430	100,000	PV
I34	Hondarribi	Hondarribi Sub 115 kV Bus	34430	20,000	PV
I35	Hondarribi	Hondarribi Sub 115 kV Bus	34430	20,000	PV
I36	Hondarribi	Hondarribi Sub 115 kV Bus	34430	80,000	PV
I37	Liatiko	Liatiko Sub 115 kV Bus	34521	20,000	PV
I38	Canaiolo	Canaiolo Sub 70 kV bus	34512	7,000	PV

Source: New Power Technologies.

Table 4: Queued California ISO Interconnection Requests (Continued)

ID	Substation	Interconnecting Bus	Bus Number	Rated Output (kW)	Type
I40	Sangiovese	Sangiovese Sub 70 kV bus	34564	40,000	PV
I41	Sangiovese	Sangiovese Sub 70 kV bus	34564	19,900	PV
I42	Sangiovese	Sangiovese Sub 70 kV bus	34564	20,000	PV
I43	Sangiovese	Sangiovese Sub 70 kV bus	34564	20,000	PV
I44	Sangiovese	Sangiovese Sub 70 kV bus	34564	20,000	PV
I45	Sangiovese	Sangiovese Jct Sub 70 kV bus	34456	20,000	PV
I46	Sangiovese	Sangiovese Jct Sub 70 kV bus	34456	20,000	PV
I47	Sangiovese	Sangiovese Jct Sub 70 kV bus	34456	20,000	PV
I48	Sangiovese	Sangiovese Jct Sub 70 kV bus	34456	20,000	PV
I49	Sangiovese	Sangiovese Jct Sub 70 kV bus	34456	20,000	PV
I50	Sangiovese	Sangiovese Jct Sub 70 kV bus	34456	5,000	PV
I51	Hron	Hron Sub 70 kV bus	34474	11,750	PV
I52	Hron	Hron Sub 70 kV bus	34474	20,000	PV
I53	Hron	Hron Sub 70 kV bus	34474	20,000	PV
I54	Hron	Hron Sub 70 kV bus	34474	-	CC
I55	Hron	Hron Sub 70 kV bus	34474	23,000	PV
I56	Hron	Hron Sub 70 kV bus	34474	169,000	PV
I57	Acolon	Acolon Sub 70 kV bus	34582	20,000	PV
I58	Acolon	Acolon Sub 70 kV bus	34582	20,000	PV
I59	Acolon	Acolon Sub 70 kV bus	34582	20,000	PV
I60	Acolon	Acolon Sub 70 kV bus	34582	20,000	PV
I61	Acolon	Acolon Sub 70 kV bus	34582	20,000	PV
I62	Acolon	Acolon Sub 70 kV bus	34582	20,000	PV
I63	Acolon	Acolon Sub 70 kV bus	34582	20,000	PV
I64	Acolon	Acolon Sub 230 kV bus	30935	300,000	PV
I65	Acolon	Acolon Sub 230 kV bus	30935	540,000	ST
I66	Acolon	Acolon Sub 70 kV bus	34582	20,000	PV
I67	Acolon	Acolon Sub 70 kV bus	34582	20,000	PV
I68	Acolon	Acolon Sub 70 kV bus	34582	8,000	PV
I69	Acolon	Acolon Sub 70 kV bus	34582	15,000	PV
I70	Acolon	Acolon Sub 70 kV bus	34582	25,000	PV
I71	Bonarda	Bonarda Sub 70 kV bus	34580	20,000	PV
I72	Bonarda	Bonarda Sub 70 kV bus	34580	20,000	PV
I73	Charbono	Charbono Sub 70 kV bus	34852	75,000	PV
I74	Semillon	Semillon Sub 70 kV bus	34562	20,000	PV
I75	Semillon	Semillon Sub 70 kV bus	34562	20,000	PV

Source: New Power Technologies.

Table 2 consists of 46 projects. New Power Technologies also evaluated some of the substation-connected projects at alternate locations within the distribution feeders served from those substations, and in a few cases, New Power Technologies evaluated feeder-connected projects at substation locations. Accordingly, several records in **Table 2** are alternate interconnection locations for individual projects. These alternates provide additional examples for evaluating the analytical approach of this study. They also offer interesting comparisons of the network impacts of a given project under different interconnection schemes.

PG&E provided additional information on the project location or interconnection location for most of the WDAT projects. Where the actual interconnection point was not specified, New Power Technologies determined an interconnecting structure for this contract based on the location of the project, as follows.

In general, New Power Technologies established network points of interconnection for feeder-connected projects by first determining or estimating the geospatial location of the project from other given or public project information (geocoding), and then determining the distribution feeder bus within the Energynet geospatial/network model that is closest to the project site. **Figure 3** illustrates the placement of Project W23 at nearby Energynet bus number 701877, which is visible in a line of Dolcetto Feeder 1102.

In some cases this mapping results in large projects (> 10 MW) connected at locations within existing distribution feeders. These interconnections are included here as additional and likely challenging distribution project interconnection cases for evaluating the analytical approach of this study. However, PG&E's normal policy would generally require projects of this size to connect to the substation via a dedicated line at distribution voltage, sometimes referred to as an *express feeder*.

For substation-connected projects, in most cases the interconnection queue specifies the high-voltage (transmission) side or low-voltage (distribution) side as the interconnection point. PG&E advised New Power Technologies that this selection is generally made by the project sponsor in the interconnection request. In practical terms, interconnection at transmission voltage could require some reconfiguration of the transmission beyond a direct tap (for example, a multiple-breaker substation switching scheme such as a ring bus or breaker-and-a-half configuration that provides redundancy and operational flexibility), and connection at distribution voltage could require replacement of the substation transformer.

Each project is incorporated in the Energynet simulation as a generating project at the specified bus number, so the impact of each project on the power delivery network is appropriate for the size and location of that project, as well as the relevant attributes of power delivery network at the point of interconnection and nearby. The interconnection points include transmission-level network nodes, such as Gamay Substation bus numbers 30900 (230 kV) and 30055 (500 kV), distribution-level substation operating buses (generally with 5xxxxx series bus numbers), and buses within individual distribution radials (generally with 7xxxxx series bus numbers). [11]

Most of the projects listed in **Table 2**, **Table 3**, and **Table 4** are identified in the interconnection queues as having a photovoltaic energy source. New Power Technologies thus modeled every project as an inverter-based power source. Further, New Power Technologies evaluated every project as operating at a fixed, unity power factor—no

11 Bus numbers in this report refer to bus numbers in the Energynet dataset provided to Energy Commission staff.

projects were modeled with absorbing reactive power at constant power factor, power factor schedules, or with active power factor or voltage control. New Power Technologies also modeled the output of each project as equal to its maximum rated output, representative of peak solar production conditions and no output degradation. New Power Technologies also assumed all of the generating projects evaluated would interconnect at 3-phase.

Figure 3: Project W23 at Bus 701877 on Dolcetto 1102 Feeder

Source: New Power Technologies.

Power Delivery Network

New Power Technologies made several notable assumptions about the power delivery network. Regarding system voltage regulation, the modeled distribution feeders contain a rich set of voltage regulation features, including substation tap changer under load (TCUL) transformers or bank voltage regulators, distribution line voltage regulators, and step-downs within the distribution feeders.

According to PG&E, in practice PG&E regulates voltage to ± 5 percent of nominal voltage on the distribution system with these line voltage regulators. PG&E may use multiple line voltage regulators in series at some weak locations to keep the steady-state voltage within limits. In this case, these voltage regulators are timed to operate sequentially to avoid hunting/fighting between the voltage regulators.

At the transmission level, voltage is regulated by the transmission-connected generators, with volt/VAR schedules provided by California ISO for the most part. Although PG&E has some automatic TCUL control capability in the transmission substations, it doesn't use it to avoid inadvertent circulating current flow.

For this study, New Power Technologies assumed all of the distribution feeder and transmission-to-distribution substation voltage regulation features could function as active voltage-regulating devices.[12] Furthermore, New Power Technologies assumed that all of these would function properly when exposed to reverse flow due to interconnected generation. As PG&E noted, the distribution feeder voltage sensing and sequential timing coordination of line voltage regulators is generally designed for unidirectional, radial operation. With reverse flow, these schemes may not work well, resulting in unintentional reactive power flow.

New Power Technologies also did not include any power generation other than existing distribution-connected generation included in the circuit data provided by PG&E, existing transmission-connected generation included in the WECC data set, and, where appropriate, the proposed wholesale PV generation interconnections described above. One consequence of this is that within the analysis none of the distribution feeders with possible WDAT PV interconnections also has nearby rotating generation providing reactive power.

Power Delivery Network Operating Conditions

In most of these results, New Power Technologies has evaluated the network impacts of PV projects at their full peak output and with the power delivery network operating under minimum daytime load conditions. New Power Technologies chose this set of conditions because where the output of a generation project is offset by local load, a simulation with peak loads may mask the impacts of a nondispatchable resource such as PV that would occur under lower load conditions.

In California, while peak PV output occurs in the hours before and after local or solar noon, system electrical load typically peaks later in the day, so the system loads likely to occur coincident with PV peak output are lower than peak loads. On a sunny, spring weekend day, loads occurring simultaneously with peak PV output could be much lower than peak

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12 Source data indicate that some of the system capacitors in fact are "fixed" and are not active system components.

loads. This choice of operating conditions for this study is nonetheless conservative, as even on a weekend day over a few hours past local noon, PV output will decrease, and loads will come up. This scenario is consistent with putting a bound on the local impact of wholesale PV projects.

As minimum daytime load is not presently a common system analysis scenario, New Power Technologies characterized the distribution portion of the model as loaded at 35 percent of its peak loads, as noted in the section "Distribution Loads" above. The transmission portion of the model was based on a light summer load regional transmission dataset, also.

From a regional perspective, where the output of a generation project adds to electric supplies attempting to reach distant urban load centers over constrained paths, a simulation under peak load conditions may be more appropriate to reveal those impacts. Again, peak PV output coincident with peak loads is conservative in that when loads typically peak, solar output is well past its peak.

In all of these results, New Power Technologies evaluated the network impacts of PV projects with all facilities in service. From a regional transmission perspective, it arguably would be appropriate to evaluate these projects as a group for the impact on contingency scenarios and under contingency conditions, even though this was outside the scope of this study.

Individual Project Grid Impact Evaluation Criteria

New Power Technologies evaluated distribution feeder-connected projects individually for the following factors. In each case the factors are evaluated at the point of interconnection of the project, as appropriate.

- Potential feeder export
- Existing reclosing scheme
- Reverse flow at voltage regulation devices
- Existing circuit voltage regulation capability
- Steady-state voltage rise/voltage limit violation at point of interconnection
- Quasidynamic voltage impact of project output variation at point of interconnection
- Potential overload of upstream circuit components under loss-of-load conditions
- Relative power system weakness at the point of interconnection

New Power Technologies did not look at the risk of an unintended island as a stand-alone criterion even in instances where PV generation exceeds local load. In a contingency event, where such an area has separated from the main part of the grid, to sustain an island, real and reactive load within the separated portion must precisely equal real and reactive generation within the separated portion at the moment of separation and beyond. In the case of these PV projects, there is no source of reactive power to match local reactive load; so even if real power load and generation did match, the island voltage would quickly collapse, generation units would trip, and current would quickly decay.[13] Also, given present practice, it is very likely that these PV units would all be equipped with active anti-islanding features (for example, direct transfer trip), which would directly trip the units in the event of a separation from the main grid primary source (generally the substation serving the feeder).

New Power Technologies did identify the presence of a reclosing scheme, specifically any reclosers serving portions of the power system with wholesale project interconnections proposed. There is, in principle, the risk that local generation could energize an island long enough for a reclosing attempt under a very rapid reclosing scheme. Identifying these affected reclosers is useful, as in practice the reclosing times for these reclosers might be reviewed and extended to a minimum of 30 – 60 seconds.

In addition to the evaluation for potential feeder export, New Power Technologies specifically identified voltage regulation points (substation or stepdown transformers and line voltage regulators) that would be subject to reverse flow. While New Power Technologies assumed these devices would operate properly under reverse flow in the system model, in practice a review of these devices would be required to ensure that they would properly sense the strong source and continue to operate properly under reverse flow.

These results do not include an evaluation of interconnections for impacts on system protection. Nonetheless, a full interconnection evaluation for projects of the type and size listed in **Table 2**, **Table 3**, and **Table 4** would in practice normally also include a review of system protection and any changes to relays or setpoints appropriate with the connection of the generation project in question.

New Power Technologies also did not consider project output relative to load or penetration as a stand-alone project evaluation criterion. Under the approach of this study, where penetration has impacts, they manifest in other criteria described here, such as the potential for feeder export or component overload.

New Power Technologies believes it is essential in evaluating distribution-connected generation to rigorously represent potential differences in project grid impacts due to

13 Cullen, et al, *Risk Analysis of Islanding of Photovoltaic Power Systems within Low Voltage Distribution Networks*, International Energy Agency, Report IEA PVPS T5-08, 2002.

differences in the characteristics of the power delivery system at the point of interconnection—specifically differences *within* a distribution feeder. These differences in project impact are distorted or lost when feeder-connected projects are equivalized at a substation bus or feeders are reduced or the analysis relies on representative feeder models.

New Power Technologies employed two measures to capture such differences. These measures are the normal rating of the most limiting line segment upstream of the point of interconnection of the project (minimum upstream rating) and a measure of the relative weakness of the network at the point of interconnection. The minimum upstream line rating will reveal a pinch point between the point of interconnection and the substation that increases the threat of an overload caused by a generation interconnection at the proposed location—if the output of the generator exceeds the minimum upstream line rating, the generator could overload the pinch point under a loss of offsetting feeder load condition. The relative system weakness at the proposed point of interconnection indicates the ability of the system to resist voltage fluctuations at that point due to variation in the output of the project—a relatively weak (or nonstiff) network at the point of interconnection may indicate that a generation project of a given size is more likely to have voltage impacts requiring mitigation. To emphasize, every location within a distribution feeder potentially has different weakness and a different minimum upstream rating. New Power Technologies does not classify or generalize feeders or systems as inherently weak or built with lower-capacity equipment. Accordingly, with consideration of either or both the minimum upstream rating and the relative system weakness at each point of interconnection, identically sized generation projects even in the same distribution feeder could be shown to have different network impacts.

To measure relative system weakness objectively at the point of interconnection, New Power Technologies used a voltage impact ratio defined as the ratio of the system primary source fault current at the interconnection point, expressed in megavolt amperes (MVA), divided by the full rated output of the project, expressed in MVA. This ratio takes into direct account the actual equivalent system impedance at the point of interconnection from the primary source (the substation) as in a stiffness ratio. It also takes into direct account the operational output of the project.

This voltage impact ratio is consistent with a true stiffness ratio, which is defined in IEEE 1547 as an indicator of the ability of the power delivery system to resist voltage deviations caused by a distributed generation project.[14] However, strictly speaking, the stiffness ratio would be evaluated with all sources of fault current at the point of interconnection rather than just the utility source. Also, a generation source of a type with high short-circuit duty

14 IEEE Std 1547.2-2008, *Application Guide for IEEE Std 1547™, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems,* Clauses 3.1.7 and 3.1.8.

will yield a lower stiffness ratio, thus potentially distorting the stiffness ratio as an indicator of the normal-condition impact of that project on system voltage.

This voltage impact ratio is intended only as a preliminary indicator of the potential impact of a project on the system voltage variability at its point of interconnection in light of the strength or weakness of the system at that point. A small ratio (evidently lower than 5 or so, based on the results presented here) indicates that the project may have an outsized influence on voltage at that location.

In *Identification of Low-Impact Interconnection Sites for Wholesale Distributed Photovoltaic Generation using Energynet Power System Simulation,*[15] New Power Technologies proposed System X/R (the total system reactance divided by the total system resistance at the point of interconnection) as an indicator of the relative weakness of the power system at the point of interconnection of a generation project. This measure used alone does not take into account the size of the generation project relative to the strength of the system at the point of interconnection. System X/R also could be nominally altered through the addition in the power system of reactive capacity without causing a real change in the weakness of the power system.

New Power Technologies also directly evaluated all projects individually for the maximum impact on power system voltage using a simulation. The test scenario assumes an output change of 100 percent of the rated output of a project before any response from nearby voltage controls. New Power Technologies refers to this impact evaluation as "quasidynamic," as it does not represent a steady-state but is not as rapidly changing as a true dynamic analysis. Given the response time for electro-mechanical controls and programmed time delays for line voltage regulators, in practical terms this quasidynamic period might range from 30 seconds to several minutes.

This set of assumptions—100 percent output change with no system voltage control response—is a conservative scenario intended to put an upper bound on the voltage impact of a project. Research has confirmed that PV generation is subject to rapid output swings, but the maximum observed variation of a PV project in less than one minute is 50 percent of rated output.[16]

Performing this evaluation under minimum daytime load conditions introduces a level of conservatism in that, at least in principle, greater local load should reduce the impact of a

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15 CEC-200-2011-014.

16 Carl Lenox (SunPower), "Variability in a Large Scale PV Installation," National Renewable Energy Laboratory, Utility-Scale PV Variability Workshop, Cedar Rapids, Iowa, October 7, 2009, http://www.nrel.gov/eis/pdfs/47514.pdf.

change in output of a distributed generator. Again, New Power Technologies believes use of this operating condition is consistent with putting an upper bound on the voltage impact of a project or projects.

Performing this evaluation under minimum daytime load conditions introduces an additional level of conservatism—the assumption that a PV project is operating at full output coincident with a minimum daytime load condition. PV projects may reach full daily output only during a short period before and after local noon, when insolation peaks. Minimum distribution loads often occur in the morning.

There is no standard against which to evaluate the impact of a project on power network voltage. To put power delivery network voltage variation in context, such networks should maintain voltage variation in distribution where power is delivered to customers within ± 5 percent of nominal voltage, consistent with the normal customer voltage variation allowed under CPUC Electric Rule 2. Many distribution voltage control schemes operate with an acceptable voltage variation dead band of ± 2 percent of nominal voltage at the point of measurement. According to PG&E, the transmission system voltage is allowed to vary in a larger range than ± 5 percent of nominal voltage because voltage is regulated in the distribution system.

A voltage sag of 15 percent of nominal voltage lasting from four cycles (at 60 Hertz [Hz]) to one minute could affect customer equipment and may be considered a *power quality incident*, having some impact on customers.[17] New Power Technologies did not directly assess such short-duration events. In these results New Power Technologies generally considered an upper-bound voltage impact of a change of 3 percent of nominal or less as acceptable. Where the quasidynamic voltage impact of a project is within this range, it is very unlikely to be the sole cause of a network voltage deviation of greater than 5 percent of nominal voltage or a power quality incident as great as 15 percent of nominal voltage.

Project Group/High-Penetration Grid Impact Evaluation

A central consideration for this study is what types of impacts on the grid should be evaluated for groups of generation project interconnections or for high-penetration conditions in addition to the project impact evaluation. In particular, while a generation interconnection may have modest grid impacts on an individual basis, the combined impact of that interconnection with others may be consequential.

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17 Larry Owens, Silicon Valley Power, SEEDZ Power Quality Workshop, June 2013.

Multiple generation project interconnections may affect the same power delivery network infrastructure, resulting in compounding grid impacts. Individual generation projects may also exhibit group interaction, which, in aggregate, can result in grid impacts. These group impacts on the grid may become evident only when generation interconnections are considered in aggregate in a regional network analysis.

Where groups of generation interconnections had (or appeared likely to have) compounding impacts, in addition to evaluating the projects individually, New Power Technologies evaluated the group in total for the following impacts on either transmission or distribution components:

- Potential distribution feeder export
- Reverse flow at voltage regulation points
- Transmission lines with reverse flow
- Overloaded lines and/or transformers under steady-state conditions
- Steady-state voltage rise/voltage limit violation

New Power Technologies also evaluated some groups of projects for these factors:

- Group quasidynamic voltage impact due to coincident output variation
- Group steady-state voltage impact due to coincident output variation

As stated, New Power Technologies did not evaluate penetration as a stand-alone grid impact factor. Where the combined output of generation interconnections is large or exceeds locally served load (high-penetration), it is arguably more likely that reverse flow or overloads under light loads could occur; however, New Power Technologies preferred to assess these impacts directly.

New Power Technologies identified instances where the combined output of a group of generation projects would cause reverse network power flow under given operating conditions, with particular emphasis on a) power export from an individual feeder, and b) reversal of the prevailing transmission power flow. For distribution feeders, and potentially for transmission lines as well, this condition is, at a minimum, a departure from the design conditions of that part of the network.

These results do not include an evaluation of individual interconnections for system protection impacts. Where the output of multiple generation projects affects the same network infrastructure, particularly where there is reverse flow, it would be appropriate to evaluate the group of projects for impact on system protection. These results also do not include an evaluation of the impacts of groups of projects on fault current. Inverter-based PV generation, the focus of this study, is not a significant source of fault current.

Reverse power flow at an active voltage-regulating device, such as a voltage regulator tap changer, step-up or step-down transformer tap changer, or substation transformer tap changer, warrants consideration even if the power flow is well within the capability of the device. If the power flow direction is reversed, these devices may fail to operate correctly or may fail to operate at all. In a distribution feeder designed for radial operation, a voltage regulator with reverse power flow sensing may misinterpret a change in power flow direction due to power generation in the feeder as a change in the location of the strong (utility) source serving the feeder. Where multiple line voltage regulators are installed in series in a feeder, these may be timed to operate sequentially—anticipating only radial power flow. As noted, New Power Technologies considered all distribution voltage regulators, step-up transformer taps, and substation transformer taps as active voltage regulation devices. Further, source data indicate that some of the line voltage regulators do, in fact, have reverse power flow sensing features. New Power Technologies' approach in this study in terms of impact assessment was to identify such devices that might be exposed to reverse flow due to the interconnection of wholesale PV. There was no attempt to discern which devices might not operate properly under reverse flow; this presumably would be a case-by-case evaluation once a potential reverse flow condition is identified. New Power Technologies also did not perform quasidynamic studies showing these devices providing multiple stages of voltage regulation with time delay. Addressing reverse flow concerns in practice would likely require such provisions for coordinating the operation of active devices under different directional power flow scenarios. Again, for the simulations, New Power Technologies assumed that all of these active voltage regulation devices would function properly when exposed to reverse flow due to interconnected generation.

New Power Technologies evaluated the potential for line or transformer overloads resulting from the combined output of groups of wholesale PV generation under loaded conditions (minimum daytime load) rather than under no-load conditions. The loading impact of an interconnected generator on a radial line with no local load establishes a theoretical upper bound on the impact of the project. For a group of projects, the analogous scenario implies loss of load on multiple feeders and possibly on multiple substations all the generators in the group remaining on—a very unlikely scenario.

For the group output variation studies, New Power Technologies assumed a coincident change of 100 percent of the aggregate rated output of the units. This is a very conservative assumption both in terms of the rapid change of one unit as noted above and 100 percent coincidence of the output change of the group projects—that is, the absence of any geographic smoothing. Research has confirmed that while individual PV projects are subject to large, rapid fluctuations in output, groups of PV projects even in close proximity exhibit a significant geographic smoothing effect,[18] damping the combined impact of the projects on the grid. One study estimates the maximum output fluctuation of a PV system at 25.7 percent of rated output per minute (consistent with the less than 50 percent of rated output per minute stated earlier), but the maximum output fluctuation of a fleet of PV systems at 2.8 percent of rated output per minute.[19]

For quasidynamic voltage impacts of project groups, New Power Technologies assumed an output change of 100 percent of the combined output of the group with no response from circuit voltage controls. For steady-state voltage impacts, New Power Technologies assumed the same 100 percent aggregate output change but allowed the taps to compensate and, in some cases, allowed changes in the line capacitors as well. As noted, New Power Technologies treated all taps and line capacitors as variable. The steady-state simulations do not take into account the time delays that may be set on some line voltage regulators.

New Power Technologies did not set out to consider a mass PV trip scenario. Ordinarily, the outage of large wholesale PV projects could be considered as regional transmission contingency scenarios, which were outside the scope of this study. However, the impact of the simultaneous trip of a group of PV projects is essentially captured in the group quasidynamic output variation scenario described above. For example, if the group of PV projects were to trip due to a momentary feeder or transmission line outage, reclosing would occur with circuit voltage controls set for voltage boost and load-masking of the now-unavailable output of those projects. The simulation of the quasidynamic voltage impact of those projects as a group expresses in percentage terms the degree to which the circuit voltage controls would be wrong under such a scenario.

The outcome of the group quasidynamic voltage impact evaluation also provides some indication of the risk of the group to system stability. If the simulation still provides a feasible power flow solution with the group dropped out, this is one indication that such a perturbation would not make the network unstable.

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18 Jan Kleissl (UC San Diego), "How Geographic Smoothing and Forecasting RD&D Can Help High Penetrations of Distributed Generation," California Energy Commission, 2011 IEPR Committee Workshop on Renewable Localized Generation, May 9, 2011, http://www.energy.ca.gov/2011_energypolicy/documents/2011-05-09_workshop/presentations/08_PIER_Kleissl_5-9-11.pdf.

19 Black & Veatch, *San Diego Distributed Solar PV Impact Study*, prepared for the University of San Diego Energy Policy Initiatives Center, draft report July 9, 2013, http://catcher.sandiego.edu/items/usdlaw/pv-impact-study-2013-draft.pdf.

As noted, from a regional perspective, the output of new wholesale generation could compete with existing supplies attempting to reach distant urban load centers over constrained paths. A related consideration in terms of regional impacts of distributed generation interconnections is potential distributed generation (DG) deliverability (Potential DGD). This is defined as the capacity available at a given substation to assign deliverable status to potential distributed generation interconnecting at or below that substation without requiring additional network upgrades and without adversely affecting the deliverability status of existing or proposed generation in the interconnection queue. An independent assessment of the network factors affecting Potential DGD at the substations relating to the wholesale PV interconnections considered in this study was outside the scope of this study. However, all of the substations listed in **Table 1** other than Kadarka, Dolcetto, Trepat, and Canaiolo are individually called out in the California ISO's assessment of Potential DGD.[20] Of those, only Aragonez had Potential DG deliverability, specifically 6.34 MW. The California ISO assessment also states generally that all DG in this part of the state will have deliverability issues. This assessment suggests that in addition to the network impacts considered in this report, most of these wholesale DG projects would require some network upgrades to obtain deliverable status (or would accept limitations on the assigned deliverability status). Other approaches actually use transmission system deliverability costs, or the cost of such upgrades, as the means to quantify the power network impacts of wholesale generation. New Power Technologies did not take this approach, and these results do not directly include such costs.

Project Grouping

New Power Technologies evaluated projects in groups composed of wholesale PV projects on a common feeder and groups composed of projects on feeders served from a common substation or to be connected at that substation. Importantly, in many cases nominally distribution or WDAT projects and nominally transmission or California ISO projects fell together in one of these groups for evaluation.

Evaluation of the Vineyard system as an integrated transmission and distribution system, particularly within the context of nominally distribution (WDAT) and transmission (California ISO) interconnections that may affect each other, reveals an additional set of project group relationships within the network that cross DPA and voltage levels.

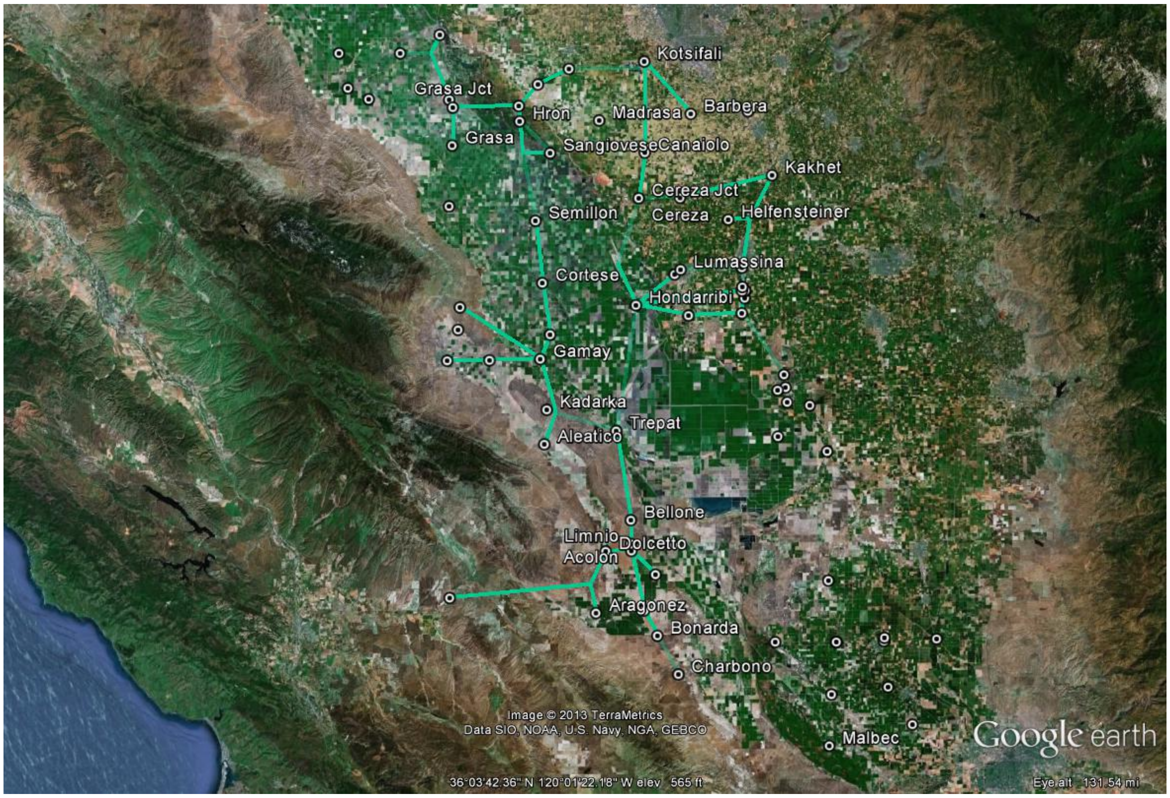
20 California ISO, *Resource Adequacy Deliverability for Distributed Generation; Revised DG Deliverability Assessment,* April 30, 2013, http://www.caiso.com/Documents/2013RevisedDeliverability-DistributedGenerationStudyResults.pdf.

The substations listed in **Table 1** are principally served at 70 kV; further, the Vineyard 70 kV system is highly networked. With open ties represented in the WECC regional transmission data sets, however, the Vineyard 70 kV system effectively breaks out into operational subnetworks, within which substations, distribution feeders, and transmission are electrically related and distinct from the rest of the network. The Vineyard 70 kV system, with the subject substations, is shown in Figure 4 with open ties partially transparent; so the operational subnetworks present in these two transmission cases are somewhat visible.

The wholesale PV interconnections within each of these subnetworks potentially affect each other and likely do not affect and are unaffected by wholesale PV interconnections outside the subnetwork. The importance of these subnetwork groups really emerges with the addition of the California ISO queue projects and the potential for interaction between interconnections at nominally distribution and transmission voltage levels. Within each of these operational subnetworks, distribution feeder-connected projects, distribution substation-connected projects, and transmission-connected projects have compounding impacts and compete for the capacity of the same network infrastructure.

Because these subnetworks cross DPAs, voltage levels, and substations, in some cases, defining them and identifying the wholesale PV projects that lie within them are actually an outcome of the study, not an element in the approach. Furthermore, New Power Technologies took the configuration of the Vineyard 70 kV network in the two WECC cases as given for this study. In reality, the network is most likely reconfigured for different operating conditions; so the subnetworks and related project groups are not static.

Figure 4: Vineyard 70 kV Transmission



Source: New Power Technologies.

New Power Technologies believes it is very significant that some evaluation is required before the potential group impact of some projects on others begins to become apparent. New Power Technologies also believes it is significant that project group interactions extend from distribution to transmission and vice-versa such that groups of projects with compounding impacts include both WDAT and California ISO projects.

Some of the queued wholesale projects are reidentified in the WDAT or California ISO queue as part of a cluster study. New Power Technologies did not take the cluster and independent annotations in the queues into consideration directly.

Methodological Changes From Phase 1 to Phase 2

Results from Phase 1 of this project are published as *Integrated Transmission Model for Assessment of Distributed Wholesale Generation*.[21] Phase 1 used a portion of the study area as a sample to, among other things, assess the feasibility of developing a model of the study area that integrates transmission and distribution to evaluate the availability and adequacy of system data for the study area. These results include the entire study area, including that portion covered in Phase 1 with several changes to the method of Phase 1. Significant methodological differences in Phase 2 from Phase 1 are described below.

California ISO Interconnection Queue Projects

New Power Technologies included the regional model characterizations of projects identified in the California ISO interconnection queue, along with interconnections from the PG&E WDAT queue. The inclusion of the California ISO projects provides interesting examples where WDAT and California ISO interconnections have compounding impacts on the same power delivery assets.

Voltage Impact Ratio

New Power Technologies evaluated distribution feeder-connected projects using a voltage impact ratio. The voltage impact ratio is intended as an indicator of the ability of the power delivery system to resist voltage impacts at the point of interconnection due to changes in the output of the interconnected generation. This ratio takes into account the size of the interconnected generator relative to the strength of the power delivery system at the point of interconnection, overcoming a limitation of the system X/R ratio used in Phase 1. As a measure of the potential operating impact of an interconnection on voltage in the power delivery system, it also avoids the distortion that would arise from differing generator fault current contributions under the stiffness ratio defined in IEEE 1547-2 and used in Phase 1.

Minimum Daytime Load Conditions

New Power Technologies has evaluated the network impacts of PV projects primarily at full output with the power delivery network operating under minimum daytime load conditions, where the results in Phase 1 were based on full PV output at peak load

21 CEC-200-2013-003, April 2013, http://www.energy.ca.gov/2013publications/CEC-200-2013-003/CEC-200-2013-003.pdf.

conditions. As noted, where the output of a generation project is offset by local load, a simulation with lower loads may more fully reveal the impacts of a nondispatchable resource such as PV. For example, New Power Technologies defines the nonexport limit of a distribution feeder for PV projects as the total feeder-connected generation that would not exceed the minimum daytime load of the feeder, less any existing feeder-connected generation. PV interconnections totaling less than the feeder nonexport limit arguably avoid and certainly reduce the chance of real power export from the feeder under most normal operating conditions. At the same time, where regional wholesale PV projects export power to remote urban load centers over constrained paths, the impact on the regional transmission system under peak conditions is also relevant.

Base Energynet Model

As noted, the base Energynet simulation model used for all simulation results presented here incorporates the westwide transmission network, the regional transmission network in California, and all of the substations and distribution feeders listed in **Table 1** as a single, fully coupled simulation model. The transmission loads and operating conditions are derived from the WECC 12ls1a case, and the distribution loads are estimated by New Power Technologies for a minimum daytime load condition.

Voltage impacts from a given event (such as a change in output of a generator), expressed as a change in nominal power system voltage, may be affected by the base voltage prior to the event. So, for clarification, in the base model for these results, the step-down substation, distribution transformer, voltage regulator taps, the distribution station, and line capacitors are all set so that the system voltage at each control point is within its specified voltage range. The resulting voltage profile is, thus, very flat—that is, with minimal deviation from nominal voltage throughout the distribution voltage ranges. By comparison, the model used in Phase 1 had all of the distribution line and substation capacitors in service. This is consistent with a peak load condition and may have had a less flat voltage profile. The voltage profile of the minimum daytime load case used as the base model for these results may indeed be flatter than the system actually normally operates under minimum daytime load conditions. Minimum daytime load is not a closely studied or design-based condition. Further, while New Power Technologies has access to and can manipulate all of the system control points in the simulation, in the physical system, operators have limited access to device status and operating conditions, and not all voltage control devices can be manipulated to fit a given operating condition.

Regional Power System Subnetworks

As stated, the inclusion in Phase 2 of proposed interconnections from both the WDAT (distribution) and California ISO (transmission) queues led to a realization that projects often are related to each other in groups that cross DPAs, substations, and voltage levels. These results include identification of these subnetworks; the proposed interconnections, both distribution and transmission, that lie within them; and the impacts of these projects as a group. Even though these subnetworks are not a static feature of the Vineyard system, the projects that lie within them certainly have compounding impacts that New Power Technologies suggests evaluating. Further, as each substation and its feeders roll up into one of these operational subnetworks, for readability these results are organized in terms of the relevant subnetwork, where the Phase 1 results were organized in terms of DPAs.

CHAPTER 3: Outcomes

Wholesale Project Grouping

The power delivery network impacts of the wholesale generation projects are listed in **Table 2**, **Table 3**, and **Table 4**. Each project is evaluated individually, within the context of the substation from which the project site is served or from which the project is connected.

In addition to evaluating projects individually, New Power Technologies attempted to assess projects as groups where there were group interactions—specifically, where the impacts of multiple projects are additive or affect the same power delivery network assets. Some obvious groupings are feeder-connected projects in one feeder and feeder-connected and substation-connected projects sharing a common substation.

With the addition of the California ISO queue projects during the study, it became apparent that groups of projects could have compounding impacts on the power delivery network or affect the same infrastructure even though they may be in feeders in different DPAs, under different substations, or from different interconnection queues altogether. These relationships became evident as projects were evaluated individually within the context of the full distribution and transmission network.

It is very significant that some evaluation is required before the potential group impact of some projects on others begins to become apparent. It is also significant that project group interactions extend from distribution to transmission and vice-versa such that groups of projects with compounding impacts include both WDAT and California ISO projects.

The following discussion considers not only wholesale interconnections by substation, but groups the substations in terms of the common subnetwork. These subnetworks are a function of the operational configuration of the regional network, particularly the 70 kV in this case, and should not be viewed as permanent characteristics of the regional network.

Some of the queued wholesale projects are reidentified in the WDAT or California ISO queue as part of a cluster study. New Power Technologies did not take the cluster and independent annotations in the queues into consideration directly.

Aleatico

Aleatico Substation serves one 21 kV distribution feeder, 2101, via a 15.8 MVA 70 kV to 21 kV substation transformer. This transformer serves about 10 MW of peak load. New Power

Technologies estimates that this transformer serves 3.4 MW under minimum daytime load conditions.

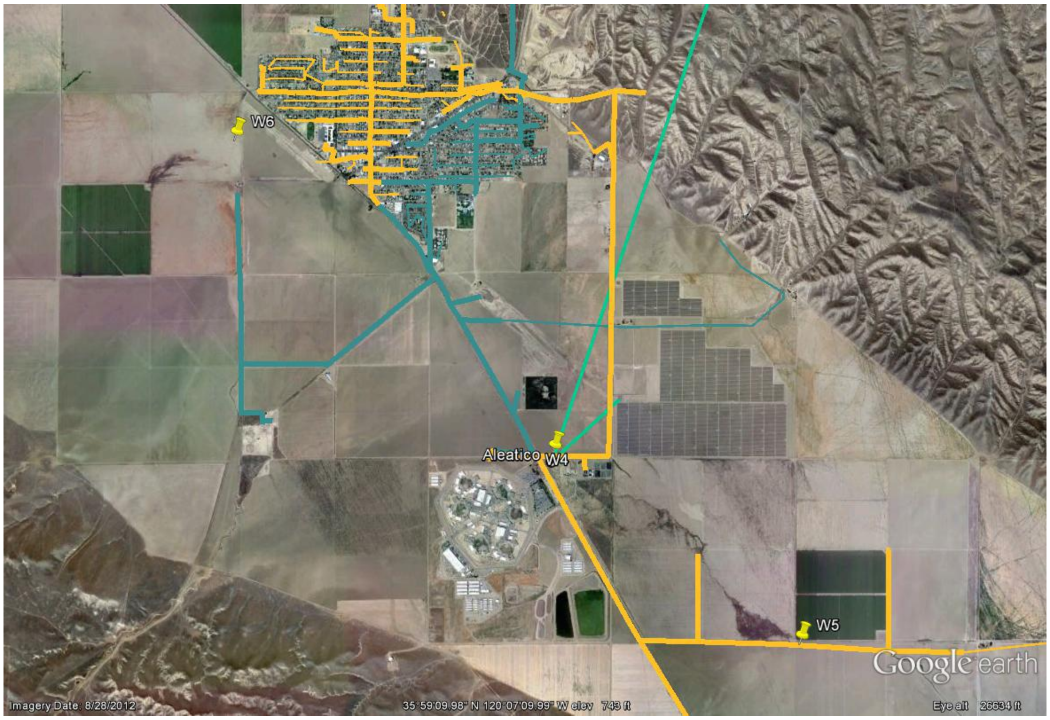
The PG&E WDAT queue identifies six wholesale generation projects for interconnection at Aleatico Substation. Three of these, identified as W1, W2, and W3, are in service and are incorporated in the regional transmission datasets. The case used to represent minimum daytime load conditions has these three projects interconnected via a tap off of the 70kV line between Aleatico and Kadarka Substation.[22] Two of the WDAT projects, W4 and W6, are identified for interconnection at the Aleatico 21 kV bus, and one, W5, is identified for interconnection at the Aleatico 70kV bus.

There are no projects in the California ISO queue identified for interconnection at Aleatico Substation.

The locations of the Aleatico projects are shown in **Figure 5**, with Aleatico Feeder 2101 and the incoming 70 kV transmission line serving Aleatico Substation visible as colored lines. New Power Technologies evaluated Project W5 in an alternate configuration as a feeder interconnection at a location in Aleatico Feeder 2101 near the project location. Project W6 is located near terminal points of Aleatico Feeder 2101 and Feeder 2104 from Kadarka Substation, which is also shown in **Figure 5** as a gray-blue line. So, New Power Technologies also evaluated Project W6 as a feeder interconnection, with the project split between Aleatico 2101 and Kadarka 2104. Together these Aleatico feeder-connected and substation-connected projects represent 139 MW.

22 The bus numbers given in **Table 2** and elsewhere for W1, W2, and W3 are represented in the 12ls1a data set. These projects are shown at bus numbers 34265, 34263, and 34257 in the 12hs4a dataset and are represented as connected to Aleatico Substation at 70 kV via a common 70 kV bus.

Figure 5: Aleatico Interconnections



Source: New Power Technologies

Distribution Feeder Interconnections

Table 5 lists the Aleatico feeder-connected WDAT projects and provides details concerning the distribution network at each point of interconnection. The interconnecting bus for the feeder-connected alternative interconnections for W4 and W6 were determined by New Power Technologies as the existing network bus closest to the project, established through geocoding the project location.

Table 5: Aleatico Feeder-Connected Project Site Characteristics

ID	Interconnecting Bus	Bus Number	Rated Output (kW)	Ckt Reverse Flow Limit (MVA)	Minimum Upstream Rating (MVA)	System X/R	Utility Source SC (MVA)	Voltage Impact Ratio
W5_alt	Bus_F255002101_ND1200174338	700396	50,000	3.64	4.6	0.64	37.8	0.8
W6 (split)	Bus_F255002101_ND1200066879	700254	10,000	3.64	7.3	1.57	29.4	2.9

Source: New Power Technologies.

Aleatico 2101 is a single-circuit served from Aleatico Substation and thus may be viewed as having circuit-level voltage regulation features, both in terms of the substation transformer tap and in terms of feeder-level regulators and capacitors.

Projects W5 and W6 at 10 MW are both far greater than the Feeder 2101 reverse flow limit. This means that under some load conditions either project under a feeder-connected scheme could induce reverse flow and export out of Aleatico 2101.

Both projects also exceed the minimum upstream line rating for the point of interconnection for each, meaning either project as feeder connected could overload Aleatico 2101.

The addition of the output of either Project W5 or W6 at 10 MW below the Aleatico transformer would induce reverse flow through the transformer under daytime minimum load conditions, and the reverse flow from Project W5 would exceed the normal rating of the transformer.

The feeder connection point for Project W5 is a very weak network location, as indicated by the voltage impact ratio of 0.8 and the system X/R of 0.64. The feeder connection point for the 10 MW portion of Project W6 is stronger but still relatively weak for a project of that size. The system X/R ratio is 1.57, but the voltage impact ratio is only 2.9.

The feeder connection point for Project W5 in Aleatico 2101 has no reclosers or voltage regulators upstream. Accordingly, interconnecting this project in this location would introduce no concerns about rapid reclosing into an energized island or reverse flow through line voltage regulators.

The feeder connection point for Project W6 in Aleatico 2101 has a recloser upstream. Accordingly, interconnection of this project in this location would require evaluation for the possibility of rapid reclosing into an energized island.

This preliminary evaluation suggests that the feeder interconnection sites for Project W5 and a 10 MW portion of Project W6 are not likely to be low-impact. Both have the likelihood of export from the circuit, overload of upstream equipment, and for both, but particularly Project W5, voltage impacts that could require mitigation.

Substation Interconnections

As noted, the Aleatico Substation transformer has a normal rating of 15.8 MVA. Accordingly, either Project W4 or W6 has the potential to overload the substation transformer. Furthermore, under minimum daytime load conditions, either project would individually cause reverse flow across the transformer, exceeding its normal rating. Project W5, identified for interconnection at the 70 kV level, would not directly affect the substation transformer. The outputs of W4, W5, and W6 are all less than the rating of the 70kV line incoming to Aleatico.

Table 6 provides the individual project voltage impacts of the Aleatico Substation wholesale projects as directly estimated at each project site using the Energynet power flow simulation. Also included are the voltage impacts of Projects W1, W2, and W3 at the interconnection points in the regional transmission model.

Table 6: Aleatico Project Voltage Impacts

					Minimum Daytime Load
ID	Interconnecting Bus	Bus Number	Rated Output (kW)	Type	Quasi-dynamic Voltage Impact (ΔV, % of Nominal)
W1	SLR6	34619	20,000	PV	3.0
W2	SLR9	34623	10,000	PV	0.0
W3	SLR3	34617	19,000	PV	3.0
W4	Bus_S2550021000_21kV_OperatingBus	500500	20,000	PV	1.2
W5	Aleatico Sub 70 kV bus	34546	50,000	PV	4.0
W6	Bus_S2550021000_21kV_OperatingBus	500500	20,000	PV	1.2
W5_alt	Bus_F255002101_ND1200174338	700396	50,000	PV	16.9
W6 (split)	Bus_F255002101_ND1200066879	700254	10,000	PV	4.4

Source: New Power Technologies.

For the feeder connected variant of Project W5, these results confirm that the project at that location would have very significant voltage impacts. A 100 percent output change of the project would cause a quasidynamic voltage change at the project site under minimum daytime load conditions equal to nearly 17 percent of nominal voltage. For feeder connection of a 10 MW portion of Project W6, these results show less voltage impact. A 100 percent output change of the project would cause a quasidynamic voltage change at the project site under minimum daytime load conditions equal to 4.4 percent of nominal voltage. Under steady-state conditions, after allowing for the operation of voltage regulation taps, the voltage impact of a 100 percent output change of the 10 MW portion of Project W6 changes voltage at the project site by 2.7 percent of nominal voltage, which might be acceptable.

Projects W4 and W6, connected at the low-voltage operating bus of Aleatico Substation, have modest voltage impacts under minimum daytime load conditions.

Existing projects W1, W3, and W5 have meaningful voltage impacts under minimum daytime load conditions—in each case, a 100 percent output change of the project would cause a 3 – 4 percent change in nominal transmission voltage at the project site. Project W2, which is smaller, has no impact on voltage under such an event.

DG Interconnection Groups

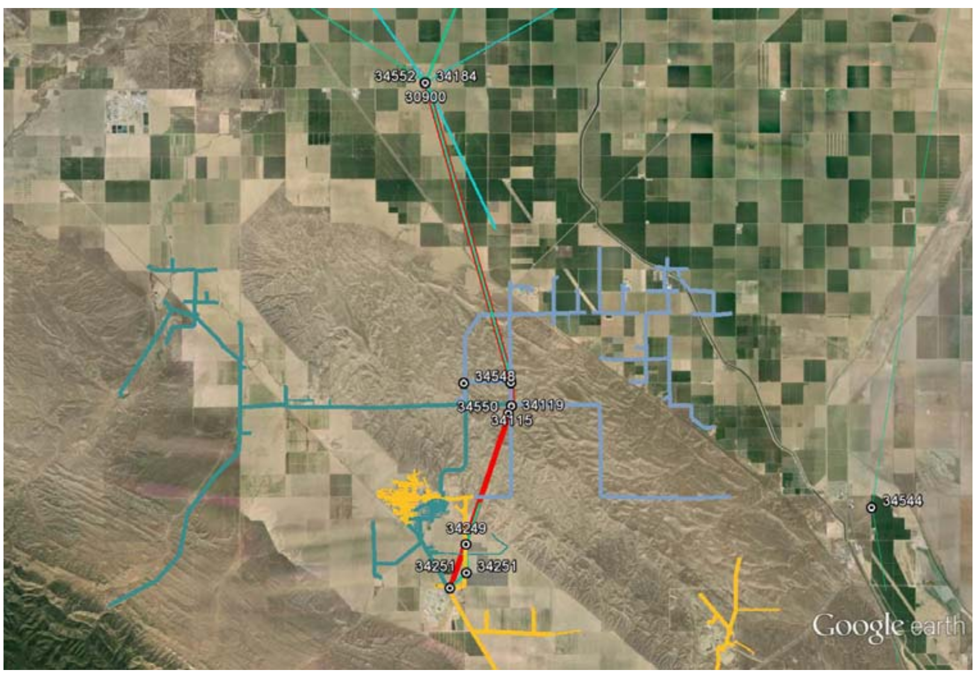
As any of the Aleatico projects identified for interconnection at the distribution voltage level (for example, W4, W6, and W5 in its alternate configuration) has output exceeding the normal rating of the substation transformer, these projects as a group would, of course, also exceed the rating of the transformer.

Aleatico is served at the 70 kV level essentially radially, as shown in **Figure 4** and **Figure 5**. Accordingly, all of the Aleatico interconnections at either distribution or transmission voltage potentially affect the same upstream 70 kV transmission infrastructure. Existing projects W1, W2, and W3 are all PV projects, which would presumably operate during most daytime conditions. As a group, they represent 49 MW, exceeding the normal ratings of some of the 70 kV lines between Aleatico and Gamay Substations. Under light load conditions, these projects operating as a group do result in reverse flow to Gamay (shown as yellow highlight), and flow exceeding the normal rating (and very near the maximum rating) of one of the 70kV lines between Aleatico and Kadarka (shown as red highlight).

On a steady-state basis, the combined output of the three projects does not cause any voltage violations in the transmission system. A simultaneous 100 percent change in the output of the three projects results in a quasidynamic voltage change of 3.6 percent of nominal voltage evaluated at the tap that is common to the three projects.

If the output of W1, W2, and W3 is taken as a given, projects W4, W5, and W6 individually or as a group compound the reverse flow and potential overload of the upstream 70 kV system.

Figure 6: Aleatico Substation Project Impacts



Source: New Power Technologies.

With projects W1, W2, W3, W4, W5, W6 operating as a group, there is, of course, a significant overload of the 70 kV transmission between Aleatico and Gamay, with a net of 129 MW flowing over a line with a 43.5 MVA maximum rating. The extent of this overload is shown in **Figure 6** as a red highlight. There is a very slight elevation of steady-state voltage at the 70 kV bus at Aleatico Substation, demonstrating the ability of the system to maintain voltage. This overload under minimum daytime load conditions would persist under peak load conditions, though there is no voltage elevation under peak conditions.

A simultaneous 100 percent output change of these projects as a group has a quasidynamic impact on voltage of 4.4 percent of nominal voltage.

Kadarka

Kadarka Substation serves two distribution feeders, 1101 at 12 kV nominal and 2104 at 21 kV nominal. Kadarka Substation has one 10.6 MVA 70 kV to 12 kV transformer bank, with the voltage of Feeder 2104 stepped up in the feeder. New Power Technologies estimates the load served by this transformer at 2.6 MVA under daytime minimum load conditions.

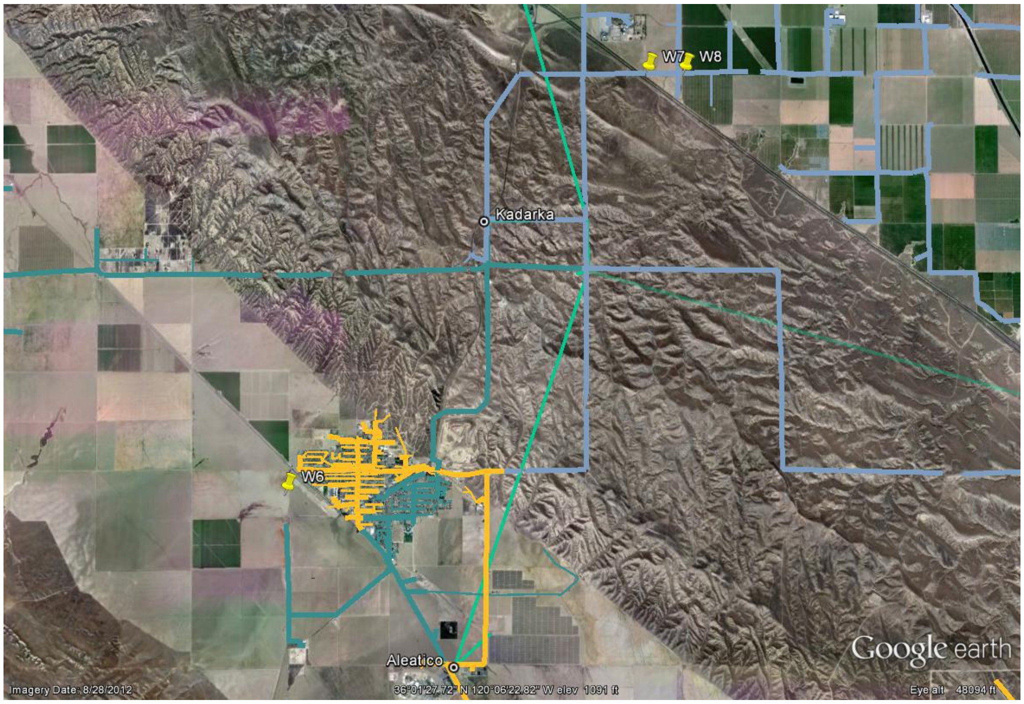
The PG&E WDAT queue identifies four wholesale generation projects for interconnection at Kadarka Substation; however, New Power Technologies evaluated two of these, W9 and W10, in connection with Trepat Substation in light of the geocoded location. Projects W7 and W8 are both identified for interconnection at locations within Feeder 1101. New Power Technologies also evaluated as alternate interconnections a share of Project W6 as connected within Feeder 2104 at two points.

There are no projects in the California ISO queue identified for interconnection at Kadarka Substation.

The locations of the Kadarka interconnections are shown in **Figure 7**, with the Kadarka distribution feeders and the incoming 70 kV transmission line serving Kadarka and Aleatico shown as colored lines. Aleatico Feeder 2101 is also shown.

As noted, Project W6 is located near terminal points of Kadarka Feeder 2104 and Aleatico Feeder 2101. New Power Technologies also evaluated an alternate configuration of Project W6 as a feeder interconnection, with the project divided between Aleatico 2101 and Kadarka 2104.

Figure 7: Kadarka Interconnections



Source: New Power Technologies.

Distribution Feeder Interconnections

Table 7 lists the Kadarka feeder-connected WDAT projects and details the distribution network at each point of interconnection. The interconnecting buses for projects W7 and W8 were determined by New Power Technologies as the existing network bus closest to each project, established through geocoding the location of the project. There are two alternative interconnecting buses for the portion of W6 in Kadarka Feeder 2104. One, Bus 700955, is the bus nearest the project site, and one, Bus 701135, is at a location southwest of the project site where the feeder is less weak and more capable of supporting the interconnection.

Table 7: Kadarka Feeder-Connected Project Site Characteristics

ID	Interconnecting Bus	Bus Number	Rated Output (kW)	Ckt Reverse Flow Limit (MVA)	Minimum Upstream Rating (MVA)	System X/R	Utility Source SC (MVA)	Voltage Impact Ratio
W7	Bus_F252731101_swt_21	700617	3,000	1.73	10.1	2.46	42.0	14.0
W8	Bus_F252731101_ND1200027614	700660	3,000	1.73	10.1	2.46	40.9	13.6
W6 (split)	Bus_F252732104_ND1200034955	700955	10,000	1.10	4.0	0.75	13.1	1.3
W6 (split)	Bus_F252732104_ND1200180798	701135	10,000	1.10	4.0	2.64	32.6	3.3

Source: New Power Technologies.

Kadarka Feeder 1101 has several line voltage regulators. Kadarka Feeder 2104 has in-line voltage step-up and step-down to and from 21 kV. Therefore, the existing system has circuit-level voltage management capability.

Projects W7 and W8 both exceed the Feeder 1101 reverse flow limit, meaning either one is capable of inducing export from the feeder under some load conditions. The 10 MW portion of Project W6 is well over the Feeder 2104 nonexport limit, meaning this project interconnected in Feeder 2104 would cause reverse flow and export from the circuit under some load conditions.

Projects W7 and W8 do not exceed the minimum upstream line rating for the point of interconnection for each, meaning neither project is capable of causing an overload of Kadarka 1101. A 10 MW share of Project W6 easily exceeds the minimum upstream line rating, meaning this interconnection has the capability of overloading the feeder under some load conditions. The primary difference between the interconnection at Bus 700995 and at Bus 701135 is that the latter has only a few sections of 4.0 MVA conductor. So while both locations have a chance of an overload, the affected line length for the Bus 701135 interconnection is much less.

The feeder connection points for Projects W7 and W8 are strong, with voltage impact ratios of 14.0 and 12.6, respectively. The connection point for Project W6 at Bus 700955 is very weak, with a voltage impact ratio of 1.2. The connection point for Project W6 at Bus 701135 is stronger, with a voltage impact ratio of 3.3.

The connection points for Projects W7 and W8 in Kadarka 1101 have no reclosers or voltage regulators upstream. Accordingly, interconnecting these projects in this location would introduce no concerns about rapid reclosing into an energized island or reverse flow through line voltage regulators.

The two alternate connection points for Project W6 in Kadarka 2104 have two reclosers upstream. Accordingly, interconnection of this project in either location would require evaluation for the possibility of rapid reclosing into an energized island. The 12 kV to 21kV step-up transformer in Kadarka 2104 also lies upstream of both connection points; thus, the possibility of reverse flow at that voltage regulation point would require evaluation.

The addition of the output of Projects W7 or W8 or the two variants of the 10 MW split of Project W6 below the Kadarka transformer would induce reverse flow through the transformer under daytime minimum load conditions, but none would exceed the normal rating of the transformer.

This preliminary evaluation suggests that the feeder interconnection sites for Projects W7 and W8 are likely to be low-impact. There is some risk of reverse flow from either project, but neither is likely to cause equipment overload or significant voltage impacts. The two feeder locations for interconnection of a 10 MW portion of Project W6 are less likely to be low-impact. Interconnecting the project at the Bus 700955 location would likely cause overloads of upstream lines, significant voltage impacts, and feeder export. The Bus 701135 location is also likely to cause reverse flow and overloads of upstream equipment. However, there are fewer affected lines. This location may have voltage impacts that are manageable.

Table 8 provides the project voltage impacts of the Kadarka Substation wholesale projects as directly estimated at each project site using the Energynet power flow simulation.

Table 8: Kadarka Project Voltage Impacts

					Minimum Daytime Load
ID	**Interconnecting Bus**	**Bus Number**	**Rated Output (kW)**	**Type**	**Quasi-dynamic Voltage Impact (ΔV, % of Nominal)**
W7	Bus_F252731101_swt_21	700617	3,000	PV	2.2
W8	Bus_F252731101_ND1200027614	700660	3,000	PV	2.2
W6 (split)	Bus_F252732104_ND1200034955	700955	10,000	PV	11.4
W6 (split)	Bus_F252732104_ND1200180798	701135	10,000	PV	2.0

Source: New Power Technologies.

For Projects W7 and W8, these results confirm that these two projects at feeder interconnections have modest voltage impacts. A 100 percent output change of the project under minimum daytime load conditions would cause a quasidynamic voltage change at each project site equal to less than 2.5 percent of nominal voltage. For the 10 MW share of Project W6, results confirm the difference between the two alternate interconnection points. The weaker Bus 700955 location would see significant voltage impacts—a 100 percent output change of the project under minimum daytime load conditions would cause a quasidynamic voltage change at the project site equal 11.4 percent of nominal voltage. The stronger Bus 701135 location would see manageable voltage impacts—a 100 percent output change of the project under minimum daytime load conditions would cause a quasidynamic voltage change at the project site equal to 2.0 percent of nominal voltage.

The two alternate interconnection locations for Project W6 in Kadarka Feeder 1104 represent a good example of identical projects connected at different locations within the same circuit having very different voltage impacts. In this case, the project in one location could swing network voltage by 11 percent of nominal, and in another location, the project moves network voltage by 2 percent of nominal. The difference is due to the difference in relative weakness of the network at the two interconnection points. Such differences might be distorted where assumptions are made on the internal characteristics of the feeder, and lost entirely where the project is represented as connected at the substation.

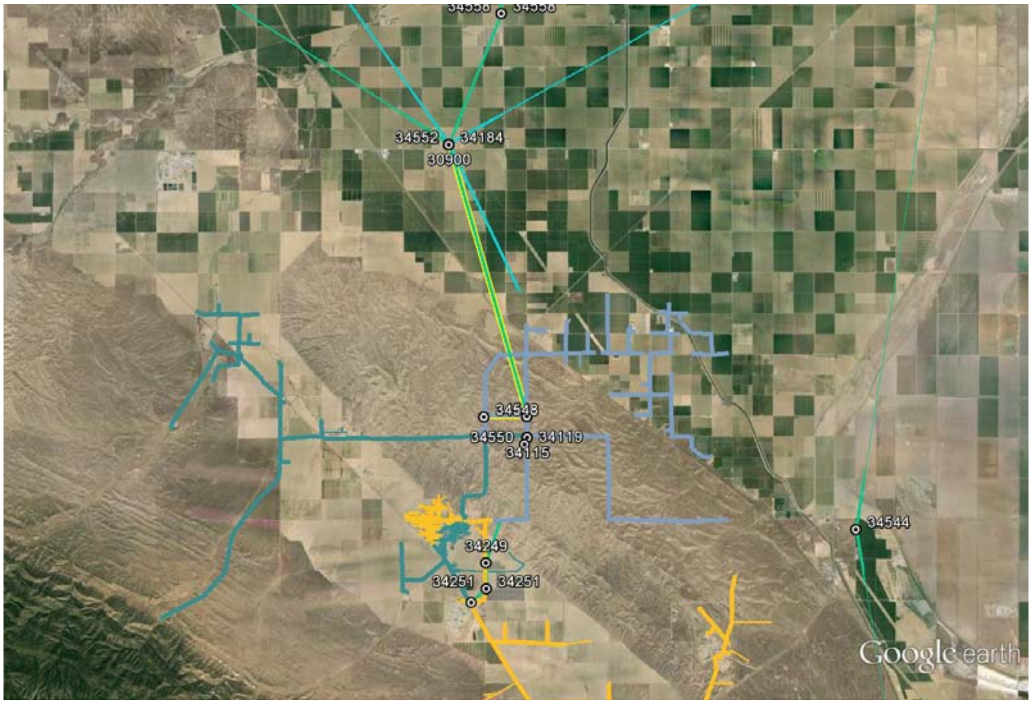
DG Interconnection Groups

Projects W7 and W8 connected in Feeder 1101 appear individually to be feasible interconnections. These two projects as a group represent 6,000 kilowatts (kW); they also share a common path to the substation even though they have different points of interconnection within the feeder, as shown in **Figure 7**. Their combined output would easily exceed the circuit nonexport limit and minimum upstream line rating, creating a greater possibility of export from the circuit under low load conditions and overload of Feeder 1101 under loss of feeder load conditions. These projects as a group would also result in reverse flow at the Kadarka Substation transformer under minimum daytime load conditions—that is, the combined output exceeds the combined load of the Kadarka feeders under those load conditions.

A simultaneous 100 percent change in the output of Projects W7 and W8 results in a quasidynamic voltage change of 3.9 percent of nominal voltage evaluated at the weaker W8 location.

A group composed of Project W6 represented as split and feeder-connected in Aleatico 1201 and in Kadarka 1204 at Bus 711135 has the following impacts. As indicated, the interconnections in both circuits cause reverse flow in both circuits and overloads some lines in Kadarka 1204. The quasidynamic voltage impact of a simultaneous 100 percent output change of the two interconnections is 3.4 percent of nominal voltage at the project site in Aleatico 1201 and 2.1 percent of nominal voltage at the project site in Kadarka 1204, in each case evaluated under minimum daytime load conditions with projects W1, W2, and W3 operating. Both the Project W7 and W8 group and the W6 group would also cause reverse flow on the 70 kV transmission lines from Kadarka to Gamay, shown as yellow highlight in **Figure 8**.

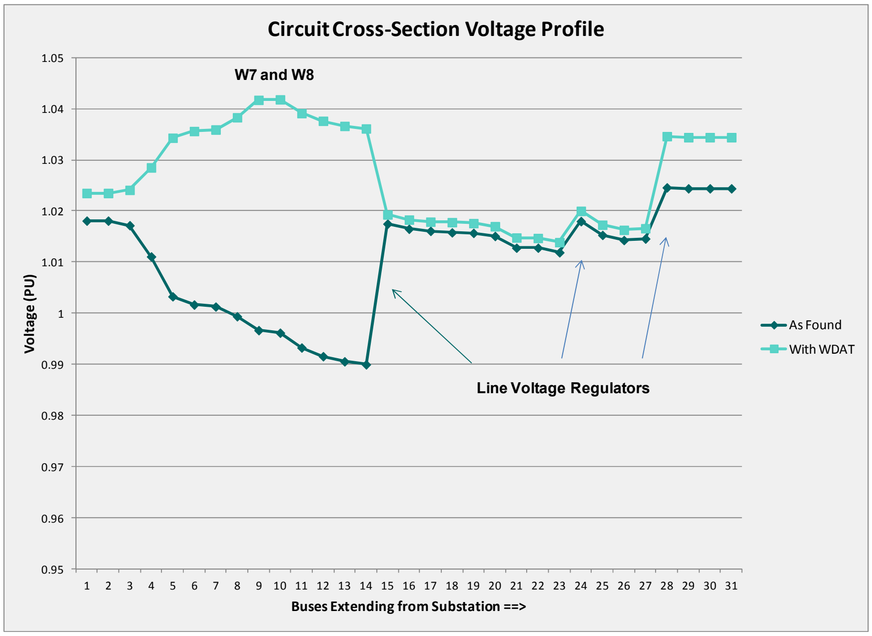
Figure 8: Kadarka Substation Project Impacts



Source: New Power Technologies.

Projects W7 and W8 also provide a good example of the interplay between feeder features and interconnection impacts, underscoring the benefit of evaluating feeder interconnections in detail. **Figure 9** shows the peak load voltage profile of Kadarka Feeder 1101 as found and with Projects W7 and W8 operating. Under the as-found condition, the feeder voltage decreases as the feeder extends from the substation, with voltage boosts provided by three line voltage regulators. The output of the two generating projects W7 and W8 increases the voltage at the point of interconnection, nominally Buses 9 and 10 in **Figure 9**, as expected. However, the line voltage regulators within the circuit can compensate such that through most of the circuit and at the substation, there is very little net voltage impact.

Figure 9: Kadarka Voltage Profile and Project Impact



Source: New Power Technologies.

Semillon

There are two projects in the California ISO queue identified for interconnection at Semillon Substation at 70 kV, Projects I74 and I75, 20 MW each. Considering the network at 70 kV and higher, these projects lie in the same operational subnetwork as the Aleatico and Kadarka projects.

Table 9 provides the project voltage impacts of the Semillon Substation wholesale projects as directly estimated at each project site using the Energynet power flow simulation. In terms of power flow, even though the output for these projects far exceeds the local load within the 70 kV system under minimum daytime load conditions, most of the output is exported to the 115 kV portion of the Vineyard transmission system across the Semillon 115kV/70kV transformer.

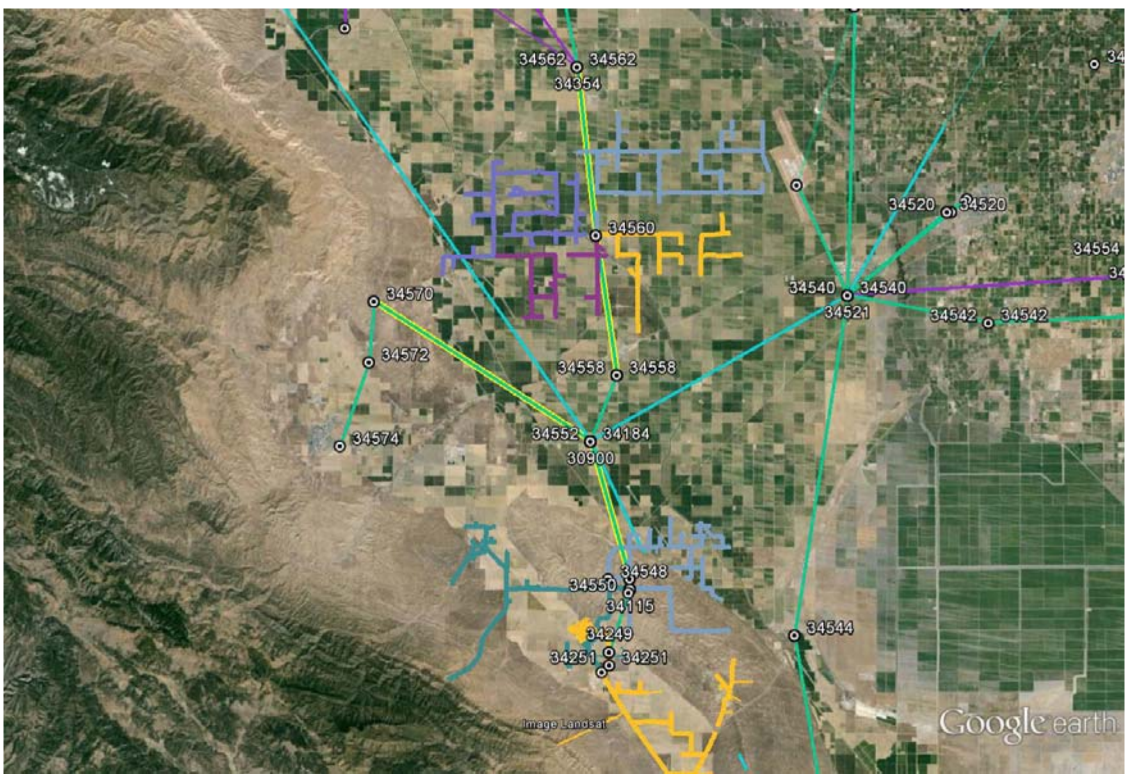
Table 9: Semillon Project Voltage Impacts

					Minimum Daytime Load
ID	Interconnecting Bus	Bus Number	Rated Output (kW)	Type	Quasi-dynamic Voltage Impact (ΔV, % of Nominal)
I74	Semillon Sub 70 kV bus	34562	20,000	PV	0.5
I75	Semillon Sub 70 kV bus	34562	20,000	PV	0.5

Source: New Power Technologies.

Under minimum daytime load conditions, these projects also cause reverse flow in several places in the 70 kV network. **Figure 10** shows Semillon substation as Bus 34562 and the reverse flow resulting from these projects in the 70 kV network as yellow highlights.

Figure 10: Semillon Substation Project Impacts



Source: New Power Technologies.

Gamay 70kV Operational Subnetwork

As noted, Aleatico and Kadarka Substations and the feeders in the Kadarka DPA are served from Gamay Substation at 70 kV. With an open 70 kV tie between Kadarka and Trepat, Trepat Substation and the feeders are electrically distinct, even though they are nominally included in the Kadarka DPA.

Accordingly, for this study, New Power Technologies found that the Aleatico, Kadarka, and Semillon interconnections discussed above should be evaluated in a common subnetwork group under Gamay 70 kV. This subnetwork is shown in **Figure 11**. The 70 kV lines tying the substations in the subnetwork are shown in turquoise, and the distribution feeders of each substation are shown in various colors. The open 70 kV tie between Kadarka and Trepat is represented as a partially transparent 70 kV line. The network below Gamay 70 kV is served from Gamay Substation via a 180 MVA 230/70 kV transformer.

This subnetwork also includes Semillon Substation as it is separated from Sangiovese Substation by an open 70 kV tie. Semillon Substation is also separately served from the 115 kV level, so the Gamay 70kV subnetwork is not entirely electrically independent. However, under the minimum daytime load base case, the Semillon 115/70 kV transformer is shown backfeeding from 70 kV to 115 kV, even with no added wholesale PV output. This backfeed increases slightly with existing Projects W1, W2, and W3 operating, as the Aleatico-Kadarka-Gamay 70 kV line reverses flow to Gamay.

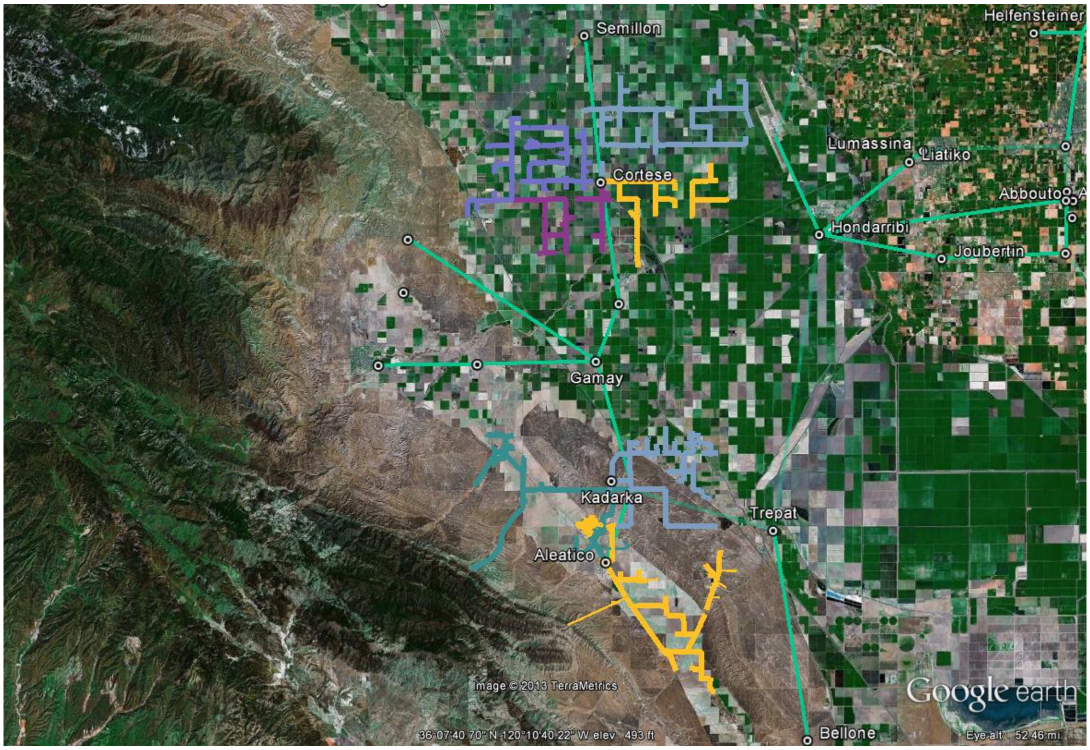
Cortese Substation serves four nominally 12 kV distribution feeders, 1101, 1102, 1103, and 1104, also shown in **Figure 11**. Cortese Substation and the feeders are also served from Gamay Substation at 70 kV and belong electrically in the same subnetwork, even though the feeders are nominally included in Gamay DPA.

Gamay 70 kV also serves Caladoc #1 and Caladoc #2 Substations, which lie to the west and northwest of Gamay Substation in **Figure 11**. New Power Technologies did not include the feeders for these substations in this study as they were outside the originally identified DPAs.

Gamay Substation nominally also directly serves a set of 12 kV distribution feeders, which are included in Gamay DPA. However, these feeders are served separately from 230 kV and are electrically distinct from the Gamay 70 kV subnetwork.

Most importantly, examination of **Figure 7**, **Figure 8**, and **Figure 10** shows that the Aleatico, Kadarka, and Semillon projects all affect the same 70 kV lines in and around Gamay 70kV.

Figure 11: Gamay 70 kV



Source: New Power Technologies.

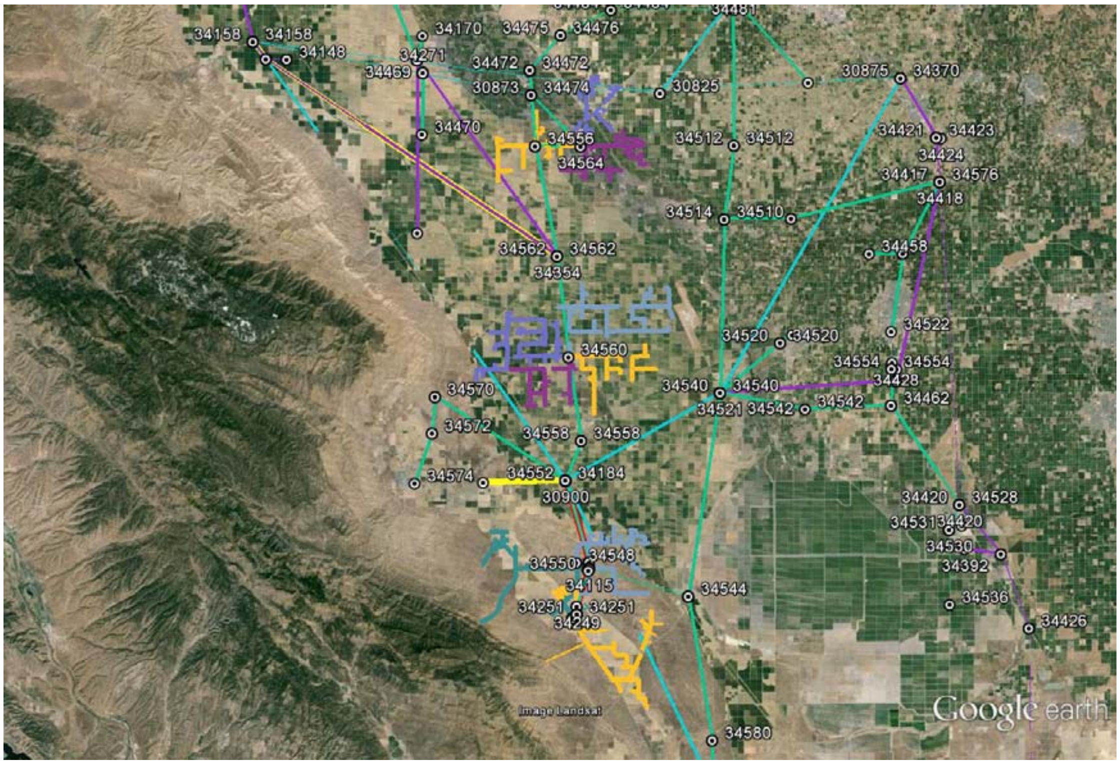
The Cortese feeders are included in the Vineyard Energynet model as they are part of Gamay DPA; however, there are no projects in the WDAT or California ISO queues identified for Cortese Substation or the feeders.

The Caladoc #1 and Caladoc #2 Substations that lie to the west and northwest of Gamay Substation contain enough generation to offset the load under minimum daytime load conditions, and these paths export power to Gamay 70 kV. The California ISO queue identifies additional interconnections totaling about 250 MW at these substations.

As a group (excluding the proposed interconnections at the Caladoc Substations), the Aleatico, Kadarka, and Semillon projects under Gamay 70 kV represent total output of about 185 MW. With all of these projects operating under daytime minimum load conditions, there is a net export to the 230kV system of 99 MW, well within the normal rating of the Gamay 230kV/70kV transformer. There is the slight steady-state voltage violation of 5.5 percent over nominal voltage at Aleatico 70 kV already noted, but no other voltage violations.

With all of these projects operating, the Aleatico-Kadarka-Gamay 70 kV path is overloaded, as previously noted and shown in **Figure 12** as red highlight. There is reverse flow elsewhere in the 70 kV system and reverse flow in the portions of the 115 kV system, shown as yellow highlights in **Figure 12**. There is also reverse flow across the Gamay 230/70kV substation transformer to 230 kV level, as previously noted.

Figure 12: Gamay 70 kV Project Impacts



Source: New Power Technologies.

The simultaneous quasidynamic loss of 100 percent of the output of all projects still yields a feasible power flow solution, with no new voltage violations. This suggests that these projects as a group do not represent a stability risk.

Gamay 12kV

Gamay Substation is a major substation within the Vineyard system, with 500 kV, 230 kV, 70 kV, and 12 kV operating voltages. Gamay directly serves four 12 kV distribution feeders, 1101, 1102, 1104, and 1105, via two 230/12 kV transformers, 44.55 MVA Bank #4 and 17.63 MVA Bank #3.

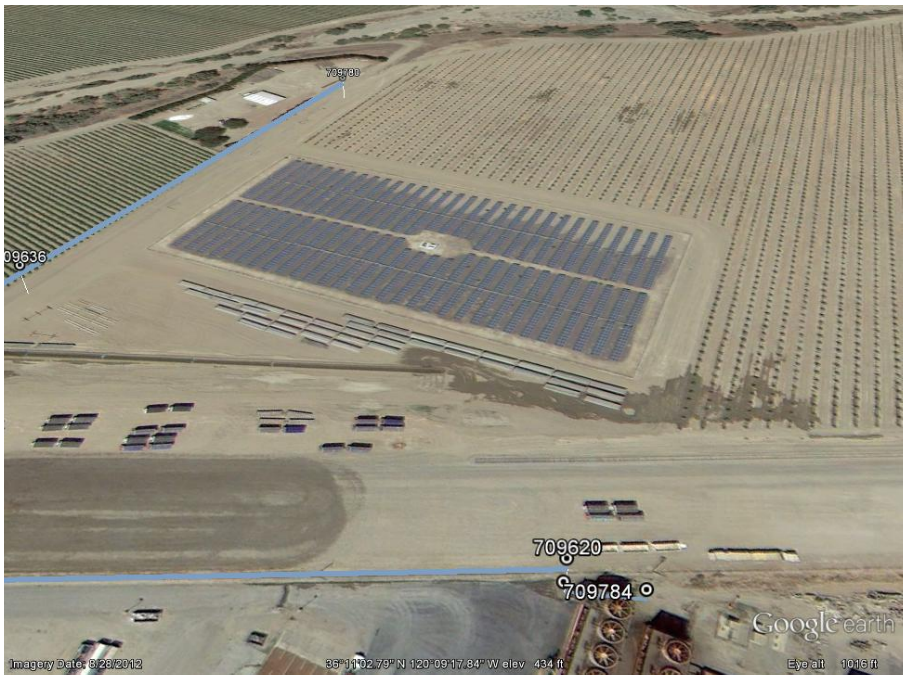
Importantly, the Gamay 12 kV distribution feeders are largely electrically separated from the 70 kV network that serves much of the Vineyard distribution system due to the direct 230kV to 12 kV step-down configuration serving the Gamay 12 kV distribution circuits.

Accordingly, New Power Technologies evaluated wholesale PV interconnections on those feeders separately from the Gamay 70 kV subnetwork group and other project groups.

Existing DG

The PG&E circuit data show an existing 53 kW PV generation project within Gamay 1102 and an existing large PV generation project within Gamay 1105. As the output of the project in Gamay 1105 in the circuit data may have been a placeholder value, New Power Technologies estimated the output at 745 kW based on size.[23] **Figure 13** shows the existing project in Gamay 1105, and **Figure 14** shows the existing project in Gamay 1102.

Figure 13: Existing PV Project in Gamay 1105 Feeder



Source: New Power Technologies.

23 Using a factor of 7 acres per 1,000 kW.

Figure 14: Existing PV Project in Gamay 1102 Feeder

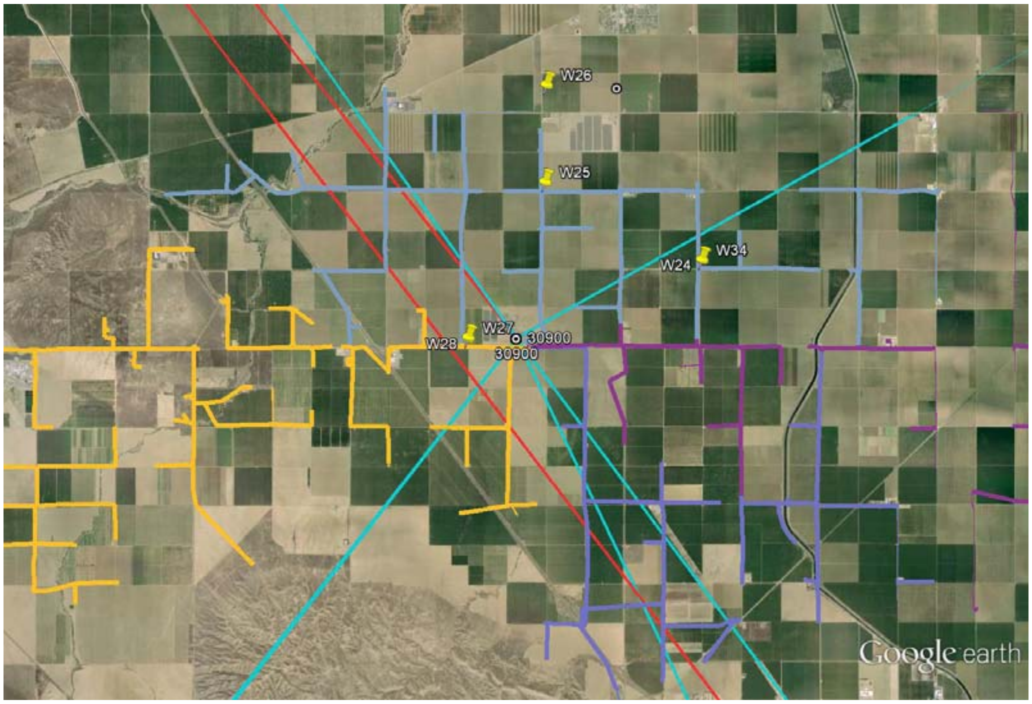
Source: New Power Technologies.

The PG&E WDAT queue identifies six projects for interconnection at Gamay 12 kV. Five of these (W34, W24, W25, W26, W27) totaling 60 MW are identified as connecting at one of the substation 12 kV operating buses. One, Project W28 at 2 MW, is identified as connecting at a feeder location within Gamay 1101.

From the California ISO queue, New Power Technologies identified eight projects, I1 through I8, connected at either the 230 kV bus or the 500 kV bus at Gamay Substation. Together, the California ISO projects represent more than 2,500 MW of capacity.

The locations of the Gamay WDAT interconnections are shown as pushpins in **Figure 15**, along with the four Gamay 12 kV feeders in various colors. Gamay Substation is identified as Bus 30900, and the red and dark turquoise lines are the 500kV and 230kV lines above Gamay 12 kV. For clarity, the 70kV lines visible in **Figure 11** are not shown in **Figure 15**.

Figure 15: Gamay 12kV Interconnections



Source: New Power Technologies.

New Power Technologies also evaluated feeder interconnection alternates for W25, W26, and W27 at locations in Gamay 1105 and a feeder interconnection alternate for W27 at a location in Gamay 1101. In each case, the feeder interconnection point was the distribution bus nearest the geocoded location of the generating project.

Feeder Interconnections

Table 10 lists the Gamay distribution feeder connection sites and provides details concerning the distribution network at the point of interconnection each project.

Table 10: Gamay Feeder-Connected Project Site Characteristics

ID	Interconnecting Bus	Bus Number	Rated Output (kW)	Ckt Reverse Flow Limit (MVA)	Minimum Upstream Rating (MVA)	System X/R	Utility Source SC (MVA)	Voltage Impact Ratio
W25 (alt)	Bus_F253931105_struc_43	709686	10,000	3.1	14.6	4.10	79.6	8.0
W26 (alt)	Bus_F253931105_swt_24	709625	5,000	3.1	7.9	2.63	18.5	3.7
W27 (alt)	Bus_F253931101_ND1200044489	707607	5,000	3.2	14.6	4.10	181.6	36.3
W27 (alt)	Bus_F253931105_struc_65	709698	5,000	3.1	4.6	1.64	28.8	5.8
W28	Bus_F253931101_ND1200044489	707607	2,000	3.2	14.6	4.10	181.6	90.8

Source: New Power Technologies.

All four Gamay distribution feeders have line voltage regulators that provide some circuit-level voltage regulation capability to accommodate the impacts of feeder-connected generation.

Projects W25, W26, and W27 in Feeder 1105 and Project W27 in Feeder 1101 all exceed the reverse flow limit for the respective circuits. This exceedance indicates that these projects connected at these locations could individually induce export from the respective feeders under minimum daytime load conditions (though not under peak load conditions). Project W28 is less than the reverse flow limit of Feeder 1101, indicating that it could not export out of Gamay 1101, even under minimum daytime load conditions.

With the exception of the alternate site for W27 in Feeder 1105, none of these projects has output that that exceeds the minimum line rating upstream of the feeder points of interconnection; so even under a full loss of circuit load, none of these projects would overload upstream components. Project W27 at 5,000 kW very slightly exceeds the 4.6 MVA rating of the most limiting upstream line segment in Feeder 1105 and could, in theory, cause a slight overload under a full loss of feeder load scenario.

W25, W27, and W28 are all in relatively strong locations within their circuits. In each case, the applicable voltage impact ratio exceeds 5.0, and in the case of W27 and W28, the voltage impact ratio is very high. So, these projects in these feeder locations are unlikely to cause significant network voltage fluctuations from variation in output. The location of W26 is relatively weak for a project of that size, and interconnecting that project in that location could result in unacceptable voltage fluctuations within the feeder.

The alternate site for W25 in Gamay Feeder 1105, Bus 798686, has no reclosers or voltage regulators upstream. Accordingly, interconnecting this project in this location would introduce no concerns about rapid reclosing into an energized island or reverse flow through line voltage regulators.

The alternate site for W26 in Gamay 1105, Bus 709625, has a recloser upstream and two voltage regulators. Accordingly, the reclosing time and voltage regulator configuration would have to be evaluated for W26 to be connected at this location.

The alternate site for W27 in Gamay 1105, Bus 709698, has a voltage regulator upstream. Accordingly, the voltage regulator configuration would have to be evaluated for W27 to be connected at this location.

The alternate site for W27 and the site for W28 in Gamay 1101 have no reclosers or voltage regulators upstream, so interconnecting either project in that location would introduce no concerns about rapid reclosing into an energized island or reverse flow through a line voltage regulator.

On the basis of this preliminary evaluation, the distribution feeder connection for W28 and the distribution feeder alternate for W27 at the same location in Feeder 1101 appear to be relatively low-impact interconnections, apart from the potential for feeder export from W27 under some load conditions. The distribution feeder alternate sites for W25 and W27 in Feeder 1105 might be low-impact interconnections subject to an evaluation of feeder export under some load conditions and the potential for voltage impacts, due to the somewhat lower voltage impact ratio. The feeder alternate for W26 is probably not a low-impact interconnection, due to the potential for voltage impacts as well as reverse flow.

New Power Technologies also evaluated the interconnection point of the existing 745 kW PV project in Gamay 1105. The output of the project alone is well under the reverse flow limit of the feeder, and the minimum upstream line rating at the project location is 5.34 MVA, well under the project output of 0.745 MW. So, this project alone is not capable of inducing export from the feeder or overloading the feeder under any load conditions. The project lies in a strong network location, with a very high voltage impact ratio for the project at that location of 37.1. The location does have a recloser and a voltage regulator upstream.

Table 11 provides the project voltage impacts of the Gamay 12 kV feeder-connected wholesale PV projects as directly estimated at each project site using the Energynet power flow simulation.

These results confirm the outcomes suggested by the voltage impact ratios depicted in **Table 10**. A 100 percent output change from either W27 or W28 at the Feeder 1101 connection point (Bus 707607) has very little voltage impact, due to the relative strength of the power delivery network at that location. At that location, a 100 percent output change of either project under minimum daytime load conditions results in a quasidynamic voltage change of less than 3 percent of nominal voltage—in fact, a change of well under 1 percent of nominal voltage. So, the maximum possible variation in the output of either project would not result in any significant circuit voltage fluctuation, even without any response from circuit voltage controls.

Table 11: Gamay Feeder-Connected Project Voltage Impacts

					Minimum Daytime Load
ID	Interconnecting Bus	Bus Number	Rated Output (kW)	Type	Quasi-dynamic Voltage Impact (ΔV, % of Nominal)
W25 (alt)	Bus_F253931105_struc_43	709686	10,000	PV	2.0
W26 (alt)	Bus_F253931105_swt_24	709625	5,000	PV	5.1
W27 (alt)	Bus_F253931101_ND1200044489	707607	5,000	PV	0.5
W27 (alt)	Bus_F253931105_struc_65	709698	5,000	PV	5.6
W28	Bus_F253931101_ND1200044489	707607	2,000	PV	0.2

Source: New Power Technologies.

For the Project W25 Feeder 1105 connection alternative, at that location a 100 percent output change of the project under minimum daytime load conditions results in a quasidynamic voltage change of 2 percent of nominal voltage. This voltage impact would be likely acceptable under some circumstances.

For the Project W26 Feeder 1105 connection alternative, with a voltage impact ratio for the project at that site well under 5.0, a 100 percent output change of the project under minimum daytime load conditions results in a quasidynamic voltage change of more than 5 percent of nominal voltage. For the Project W27 Feeder 1105 connection alternative, with a voltage impact ratio near 5.0, a 100 percent output change of the project under minimum daytime load conditions results in a quasidynamic voltage change of 5.6 percent of nominal voltage. In Feeder 1105, the W27 site is weaker in absolute terms than the W26 site, with System X/R of 1.64 at W27 Bus 709698 vs. 2.63 at W26 Bus 709625. As noted, the W27 site in Feeder 1105 lies downstream of a voltage regulator. The steady-state voltage impact of the same 100 percent output change event for this project, after allowing for the movement of voltage controls, is 4.3 percent of nominal voltage.

Projects W25 and W27 represent good examples of relatively large wholesale PV projects (10 and 5 MW, respectively) located away from the substation, where direct connection to the 12 kV distribution feeder adjacent to the project site would not risk overloading the feeder and would have manageable network voltage impacts even under light load. Both projects could result in feeder export under some load conditions, and reverse flow at the voltage regulator in Feeder 1105 would have to be evaluated.

Substation Interconnections

To evaluate the interplay of feeder-connected and substation-connected wholesale PV projects and the impact of groups of projects on upstream infrastructure, it is necessary to establish topological relationships beyond individual feeders—specifically, the topological relationships among feeders, substation operating buses, and substation transformer banks.

According to the substation single-line diagram for the Gamay Substation provided by PG&E, Gamay 12 kV Operating Bus Section D is served from Transformer Bank #3 and serves Gamay Feeders 1101 and 1102. New Power Technologies interpreted Gamay 12 kV Operating Bus Section G as served from Transformer Bank #4 and serving Gamay Feeders 1104 and 1105 via Operating Bus Sections E and F. New Power Technologies further interpreted Section D as connected to Sections E, F, and G via an open tie; in other words, Bank #3, Bus Section D, and Feeders 1101 and 1102 would operate separated from Bank #4, Bus Sections E, F, and G, and Feeders 1104 and 1105.

Under this interpretation, wholesale projects W34, W25, W26, and W27, identified in the WDAT queue as connecting at Gamay 12 kV Operating Bus Section G, would represent 40 MW of total capacity at the portion of the Gamay 12 kV operating bus served from Transformer Bank #4, rated at 44.55 MVA, and serving Gamay Circuits 1104 and 1105. Gamay 1104 and 1105 together represent roughly 6.1 MW of load under minimum daytime load conditions. Thus, in terms of loading impacts of wholesale projects W34, W25, W26 or W27, only projects W34 and W25 would be individually capable of causing reverse flow across the transformer bank under some load conditions, and none of these projects would individually be capable of exceeding the normal rating of Transformer Bank #4 under any conditions.

Likewise, under the researchers' interpretation, wholesale project W24 identified in the queue as connecting at Gamay 12 kV Operating Bus Section D represents 20 MW of capacity at the portion of the Gamay 12 kV operating bus served from Transformer Bank #3, rated at 17.63 MVA and serving Gamay Circuits 1101 and 1102. Gamay 1101 and 1102 together represent about 4.0 MW of load under minimum daytime load conditions. Thus, in terms of loading, wholesale project W24 would be capable of causing reverse flow across its transformer bank under some load conditions and could exceed the rating of Transformer Bank #3, but only under the loss of most or all distribution load.

Table 12 provides the project voltage impacts of the Gamay WDAT projects interconnected at substation operating bus sites as directly estimated using the Energynet power flow simulation. These results indicate that the voltage impact of each project, when represented as substation-connected, is very small.

Table 12: Gamay Substation-Connected Projects Voltage Impact

					Minimum Daytime Load
ID	Interconnecting Bus	Bus Number	Rated Output (kW)	Type	Quasi-dynamic Voltage Impact (ΔV, % of Nominal)
W24	Bus_S2539312000_12kV_MainBus_D	500518	20,000	PV	-0.2
W25	Bus_S2539312000_12kV_MainBus_G	500521	10,000	PV	0.0
W26	Bus_S2539312000_12kV_MainBus_G	500521	5,000	PV	0.0
W27	Bus_S2539312000_12kV_MainBus_G	500521	5,000	PV	0.0
W34	Bus_S2539312000_12kV_MainBus_G	500521	20,000	PV	0.0
I1	Gamay Sub 230 kV bus	30900	110,000	PV	0.1
I2	Gamay Sub 230 kV bus	30900	500,000	PV	0.3
I3	Gamay Sub 500 kV bus	30055	800,000	PV	-0.1
I4	Gamay Sub 230 kV bus	30900	106,800	ST	0.1
I5	Gamay Sub 230 kV bus	30900	-	CC	0.0
I6	Gamay Sub 230 kV bus	30900	106,800	ST	0.1
I7	Gamay Sub 230 kV bus	30900	600,000	CC	0.4
I8	Gamay Sub 500 kV bus	30055	250,000	PV	0.0

Source: New Power Technologies.

The feeder-connected and substation-connected alternatives for Projects W25 and W27 provide a good example of the differences that may arise in representing a feeder-connected project at the substation vs. at the circuit location. At the substation, both projects have essentially no voltage impact. However, at the in-feeder locations, both projects do have observable (though potentially acceptable) voltage impacts on the feeder, as evaluated at the point of interconnection. Moreover, due to the differences in the strength of the network at each feeder location relative to the size of each project, the voltage impacts at the feeder locations are significantly different. In fact, Project W27 has different impacts, depending on in which feeder it is represented.

Table 12 also shows the California ISO queue projects identified by New Power Technologies as connected at Gamay Substation and provides the voltage impacts of these projects. Again, the voltage impact of each of these interconnections is small.

DG Interconnection Groups

The fundamental distinction in evaluating interconnections as a group is the inquiry into circumstances where multiple projects may have interactions or compounding impacts that would require further accommodation in the grid. Thus, among the Gamay 12kV projects, New Power Technologies sought to determine if the alternate interconnection for Project W27 in Feeder 1101, which appears feasible on its own, might be precluded by the proposed interconnection of W28, also within Feeder 1101. The two projects as a group (and W27 alone) exceed the reverse flow limit of Gamay 1101, resulting in potential export from the circuit under some low load conditions. However, the two projects as a group do not exceed the minimum upstream line segment rating, so there is no risk of an overload under any load conditions. Further, a power flow simulation indicates that the combined quasidynamic voltage impact under a simultaneous 100 percent output change is a change of 1.1 percent of nominal voltage. So, the proposed interconnection of W28 within the Gamay 1101 feeder would not obviously preclude interconnection of W27 at the distribution feeder alternate location. In other words, having evaluated these two projects individually, now considering them together does not reveal any additional impacts. Interestingly, even grouped with W28, the Feeder 1101 connection of W27 seems to have lower impact than the Feeder 1105 interconnection.

So, a reasonable configuration of the Gamay WDAT projects for group evaluation is Project W25 connected within Feeder 1105, Projects W27 and W28 connected within Feeder 1101, and Projects W34, W24, and W26 connected at the respective 12 kV substation operating buses, presumably via dedicated 12 kV connections. In this configuration, W24, W27, and W28 effectively influence the portion of Gamay Substation served by Transformer Bank #3. Under minimum daytime load conditions, these projects together would cause about 23 MW of reverse flow across Transformer Bank #3 to the Gamay 230 kV bus. This would exceed the 17.63 MVA normal rating of Transformer Bank #3 by about 30 percent under daytime minimum load conditions, though under peak load conditions, the Bank #3 reverse flow condition would decrease to well under the normal rating of the transformer, or about 13 MW.

In this configuration, W25, W34, and W26 effectively influence the portion of Gamay Substation served by Transformer Bank #4. Under minimum daytime load conditions, these projects together would cause about 29.5 MW of reverse flow across Transformer Bank #4 to the Gamay 230 kV bus with no overload even under daytime minimum load conditions. A simulation of these conditions indicates that the steady-state voltage at the Gamay 12 kV operating buses under Bank #3 and Bank #4 and at the Gamay 230 kV bus remains at about 102 percent of nominal voltage (1.02 PU), so there is no steady-state overvoltage condition. Further, a simultaneous quasidynamic 100 percent output change of the group causes essentially no voltage change at the Gamay 12 kV operating buses or the Gamay 230 kV bus.

The projects under Gamay Bank #3 provide an example of an instance where a group of wholesale PV projects cause reverse flow within the power system but with no steady-state voltage violations or quasidynamic voltage concerns and, particularly, an overload condition that is load-dependent. In the case of this group of projects, the ability to curtail the output of one or more under some load conditions would more directly address the grid impacts of the projects than any voltage regulation features.

As noted, the network serving the Gamay 12 kV substation and distribution feeders is largely isolated electrically from the rest of the Vineyard network due to its direct feed from 230 kV. Gamay 12 kV is arguably not directly affected by the California ISO queue projects proposed to connect at the Gamay 230 kV bus.

The projects identified for connection at the Gamay 230 kV bus would, of course, far exceed the load served from that bus under minimum daytime load conditions. However, adding these six projects as a group has only a modest impact on the voltage at the Gamay 230 kV bus, increasing it by 0.1 percent of nominal. The greatest impact is reversal of the power flow through the Gamay 500 kV/ 230 kV transformer. Under light load conditions, the 230 kV lines at Gamay generally carry power away from the substation. With the addition of the output of the proposed wholesale generation, there are modest increases in the flows of other 230 kV lines away from the Gamay substation, but no overloaded lines. The Gamay 500 kV bus voltage is already slightly high in the WECC light load case, and the addition of the six generation projects at the 230 kV bus actually reduces the voltage slightly at the 500 kV bus.

Adding the two projects identified for interconnection at Gamay 500 kV under light load conditions substantially increases flows on the 500 kV lines leaving Gamay but causes no flow reversal or overload.

Dolcetto

Dolcetto Substation serves two 12 kV distribution feeders, 1101 and 1102, via a 5.2 MVA 70 kV to 12 kV transformer.

The PG&E WDAT queue identifies three wholesale generation projects for interconnection at Dolcetto Substation—one at a feeder location within Dolcetto 1102, identified as Project W23, and two at the 12 kV main bus at Dolcetto Substation, identified as Projects W11 and W12.

Distribution Feeder Interconnections

Table 13 lists the Dolcetto feeder-connected WDAT project and provides details concerning the distribution network at the point of interconnection.

Table 13: Dolcetto Feeder-Connected Project Site Characteristics

ID	Interconnecting Bus	Bus Number	Rated Output (kW)	Ckt Reverse Flow Limit (MVA)	Minimum Upstream Rating (MVA)	System X/R	Utility Source SC (MVA)	Voltage Impact Ratio
W23	Bus_F253451102_ND1300010673	701877	1,500	0.44	2.3	0.78	12.6	8.4

Source: New Power Technologies.

The project location is shown in **Figure 16**, along with Dolcetto Substation,with the two Dolcetto 12 kV distribution feeders shown in various colors. **Figure 16** also shows the 70 kV transmission serving Dolcetto Substation in turquoise and the 230 kV transmission serving Acolon in dark turquoise. The interconnecting bus was determined by New Power

Technologies as the existing network bus closest to the project, established through geocoding the location of the project.

Figure 16: Dolcetto Feeder Interconnections

Source: New Power Technologies

Dolcetto 1101 and 1102 both have line voltage regulators. Thus, the existing system offers some circuit-level voltage regulation capability for generation interconnections on those feeders.

Project W23 is larger than the Feeder 1102 reverse flow limit. This means that under some load conditions, W23 could induce feeder export from Dolcetto 1102.

Project W23 is well under the feeder minimum upstream line rating at the point of interconnection, meaning this project is not capable of causing an overload within Feeder 1102 under any load conditions.

Project W23 is located at a moderately strong network location for a relatively small project, as indicated by the voltage impact ratio of 8.3. In absolute terms, this location is relatively weak with a system X/R ratio well under 1.0.

Within Feeder 1102, there is a line voltage regulator between the W23 point of interconnection and the substation that could be subject to reverse flow due to the project under some load conditions.

This preliminary evaluation suggests that the feeder interconnection site for Project W23 may well be low-impact, with the potential for feeder export under some load conditions and voltage impacts that could require mitigation.

Substation Interconnections

As noted, the Dolcetto Substation transformer has a normal rating of 5.2 MVA. Accordingly, either W11 or W12, the two WDAT projects identified for interconnection at Dolcetto Substation, has the potential to overload the transformer given the stated output of 20,000 kW each.

Table 14 provides the project voltage impacts of the Dolcetto Substation wholesale projects as directly estimated at each project site using the Energynet power flow simulation.

Table 14: Dolcetto Project Voltage Impacts

					Minimum Daytime Load
ID	**Interconnecting Bus**	**Bus Number**	**Rated Output (kW)**	**Type**	**Quasi-dynamic Voltage Impact (ΔV, % of Nominal)**
W23	Bus_F253451102_ND1300010673	701877	1,500	PV	6.1
W11	Bus_S234512000_12kV_MainBus	500503	20,000	PV	-3.5
W12	Bus_S234512000_12kV_MainBus	500503	20,000	PV	-3.5

Source: New Power Technologies.

For Project W23 these results indicate that while the interconnection seems strong based on the voltage impact ratio; in fact, the project has the potential to cause relatively large voltage impacts. A 100 percent change in the output of the project would cause a quasidynamic voltage impact of more than 6 percent of nominal voltage. Under steady-state conditions (for example, after allowing the upstream voltage regulators to adjust), the impact of the same 100 percent output change event is a voltage change of 3 percent of nominal at the project site.

Project W23 provides a good example of the limitation of full reliance on voltage impact ratio as a predictor of the impact of a project on network voltage. In this case, system X/R was a better indicator. Ideally, even with a strong indication from either voltage impact ratio, system X/R, or both, the voltage impact of a project would be confirmed via a simulation.

New Power Technologies estimates the Feeder 1102 load at the substation at about 400 kW under minimum daytime load conditions; so, the output of Project W23 is large relative to locally served load. Under these load conditions, W23 results in about 1 MW of export from Feeder 1102, though the export is absorbed locally and Dolcetto Substation remains a net load.

Projects W11 and W12 result in a quasidynamic reduction in voltage at the Dolcetto 12kV bus. In either case, nearly all of the project output passes through the small substation transformer from 12 kV to 70 kV.

Trepat

Trepat Substation serves three distribution feeders, 1104, and 1106 at 12 kV nominal, and 2108 at 21 kV nominal. Trepat Substation has 10.6 and 12.5 MVA 70kV to 12 kV step-down transformers; the voltage of Feeder 2108 stepped up within the line.

The PG&E WDAT queue identifies two wholesale generation projects that New Power Technologies interpreted for interconnection at Trepat Substation. These projects, identified as Projects W9 and W10, are nominally identified in the queue for interconnection at Kadarka substation, but they are physically far from that substation. New Power Technologies modeled both projects at locations within Feeder 1106 and at the 12 kV main bus at Trepat substation, consistent with dedicated feeder interconnection, as alternative interconnections in light of size.

Distribution Feeder Interconnections

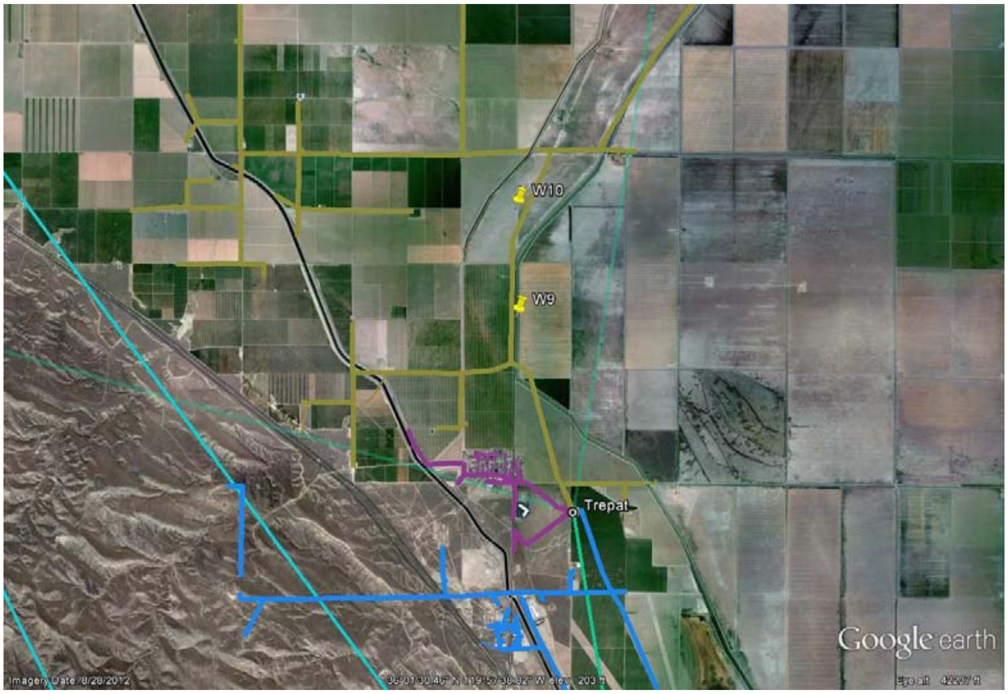
Table 15 lists the Trepat feeder-connected WDAT projects and provides details concerning the distribution network at each point of interconnection. The project locations are shown in **Figure 17** along with the three Trepat distribution feeders in various colors. In each case, the interconnecting bus was determined by New Power Technologies as the existing network bus closest to each project, established through geocoding the project location.

Table 15: Trepat Feeder-Connected Project Site Characteristics

ID	Interconnecting Bus	Bus Number	Rated Output (kW)	Ckt Reverse Flow Limit (MVA)	Minimum Upstream Rating (MVA)	System X/R	Utility Source SC (MVA)	Voltage Impact Ratio
W9	Bus_F252951106_swt_6	702517	20,000	0.9	7.9	1.72	78.1	3.9
W1	Bus_F252951106_ND1200027768	702596	20,000	0.9	7.9	1.72	45.8	2.3

Source: New Power Technologies.

Figure 17: Trepat Feeder Interconnections



Source: New Power Technologies.

Trepat 1106 and 2108 both have line voltage regulators, and Trepat 2108 also has step-up and step-down line voltage transformers. Thus, the existing system offers some circuit-level voltage regulation capability for generation interconnections at feeder sites in Trepat 1106.

Both Projects W9 and W10 far exceed the Feeder 1106 reverse flow limit, meaning that as feeder interconnections, these projects are likely to induce export out of Feeder 1106 under some load conditions.

Both projects are also well over the minimum upstream line rating at each point of interconnection, meaning these projects are capable of causing an overload under some load conditions.

The feeder interconnection locations for both projects are moderately strong network locations, considering the system X/R ratio; however, based on the voltage impact ratio, both feeder locations are weak, considering the size of the projects.

The feeder sites for W9 and W10 in Trepat 1106 have no reclosers or voltage regulators upstream; so interconnecting either project in the respective locations would introduce no concerns about rapid reclosing into an energized island or reverse flow through a line voltage regulator.

This preliminary evaluation suggests that the feeder interconnection sites for Projects W9 and W10 are not low-impact interconnections, with the potential for overloads, significant voltage impacts, and feeder export.

Substation Interconnections

As noted, the Trepat Substation transformers have nominal ratings of 10.6 and 12.9 MVA. These are very small in an system where 10-20 MW wholesale PV projects are being proposed for interconnection. In this case, either Project W9 or W10 has the capability to overload either substation transformer.

Table 16 provides the project voltage impacts of the Trepat Substation wholesale projects as directly estimated at each project site using the Energynet power flow simulation.

Table 16: Trepat Project Voltage Impacts

					Minimum Daytime Load
ID	**Interconnecting Bus**	**Bus Number**	**Rated Output (kW)**	**Type**	**Quasi-dynamic Voltage Impact (ΔV, % of Nominal)**
W9	Bus_F252951106_swt_6	702517	20,000	PV	7.6
W10	Bus_F252951106_ND1200027768	702596	20,000	PV	9.8
W9_alt	Bus_S2529512000_12kV_MainBus_D	500505	20,000	PV	2.7
W10_alt	Bus_S2529512000_12kV_MainBus_E	500507	20,000	PV	3.3

Source: New Power Technologies.

For the feeder interconnections of Projects W9 and W10, these results confirm that these locations are very weak for projects of this size. A 100 percent change in the output of either project would cause a quasidynamic voltage change of nearly 8 percent of nominal voltage for Project W9 and nearly 10 percent of nominal voltage for Project W10, as it is farther from the substation.

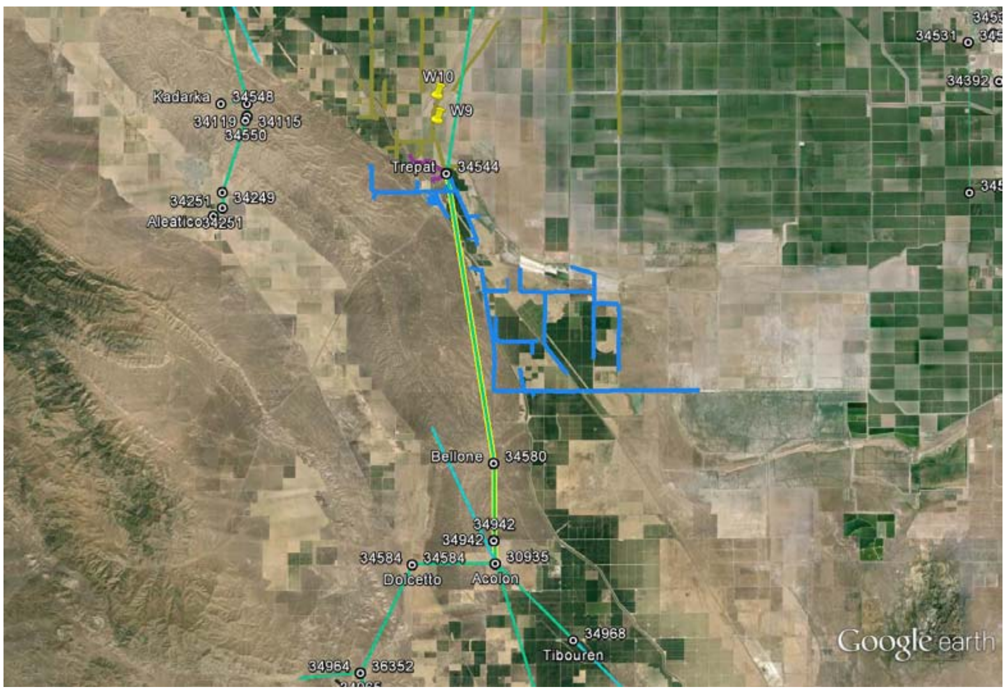
These results indicate that even 12 kV substation bus interconnections of Projects W9 and W10 have relatively large voltage impacts. A 100 percent change in the output of either project would cause a quasidynamic voltage impact of more than 2.5 percent of nominal voltage at the substation.

The feeder-connected variants of Projects W9 and W10 provide a good example of the limitation system X/R used alone as a predictor of the impact of a project on network voltage. In this case, voltage impact ratio was a better indicator of these weak interconnections. Ideally, even with a strong indication from either voltage impact ratio, system X/R, or both, the voltage impact of a project would be confirmed via a simulation, as was done here.

DG Interconnection Groups

Considered as a substation group, Projects W9 and W10 have additional regional impacts. However, with open 70 kV ties, Trepat is served essentially radially from Acolon Substation, which is a major regional substation, and the impacts do not extend beyond this point. The combined output of these projects would reverse the flow at 70 kV from Acolon Substation to Trepat Substation via Bellone Substation, shown as yellow highlight in **Figure 18**. Under daytime minimum load conditions, there is also a slight overload of the 70 kV line between Trepat and Bellone that would be relieved under heavier load conditions. These projects also elevate the voltage in that radial 70 kV transmission path by as much as 6.4 percent of nominal at Trepat Substation, with the impact declining to an increase of 1.6 percent of nominal at Bellone Substation and no change at Acolon Substation at the 70 kV level. On a steady-state basis, it is possible to avoid any voltage violation at the 12kV bus at Trepat via the substation transformer taps.

Figure 18: Trepat Project Impacts



Source: New Power Technologies.

Bonarda

Bonarda Substation serves two distribution feeders, 1102 at 12 kV nominal and 2101 at 21 kV nominal. Bonarda substation has a 12.5 MVA 70 kV to 12 kV step-down transformer; the voltage of Feeder 2101 is stepped up within the line.

The PG&E WDAT queue identifies three wholesale generation projects for interconnection at Bonarda Substation. Two projects are indentified for interconnection at distribution feeder locations—W14 in to a location in Feeder 2101, and W22 to a location in Feeder 1102. One project, W13, is identified for interconnection at the Bonarda 12 kV main bus.

The California ISO queue identifies two projects for interconnection at Bonarda Substation—Project I71 at 70kV and Project I72 on the Bonarda-Charbono 70 kV line.

Distribution Feeder Interconnections

Table 17 lists the Bonarda feeder-connected WDAT projects and provides details concerning the distribution network at each point of interconnection. The project locations are shown in **Figure 19**, along with the two Bonarda distribution feeders in various colors. In each case, the interconnecting bus was determined by New Power Technologies as the existing network bus closest to each project, established through geocoding the project location.

Table 17: Bonarda Feeder-Connected Project Site Characteristics

ID	Interconnecting Bus	Bus Number	Rated Output (kW)	Ckt Reverse Flow Limit (MVA)	Minimum Upstream Rating (MVA)	System X/R	Utility Source SC (MVA)	Voltage Impact Ratio
W14	Bus_F254682101_ND1300248905	706073	12,000	1.32	11.9	1.44	49.2	4.1
W22	Bus_F254681102_ND1300042518	705602	10,080	1.08	2.6	1.00	15.0	1.5

Source: New Power Technologies.

Figure 19: Bonarda Interconnections

Source: New Power Technologies

Bonarda 1102 has several line voltage regulators, and Bonarda 2101 has step-up and step-down line voltage transformers. Thus, the existing system offers some circuit-level voltage regulation capability for generation interconnections in those circuits.

Projects W14 and W22 are both well over the reverse flow limits of the respective feeders, meaning that both projects have the ability to induce export out of the respective feeders under some load conditions.

Both projects are also over the minimum upstream line rating for the point of interconnection of each project. Thus, these projects are capable of causing an overload of the upstream lines, though for Project W14 this could occur only under essentially full loss of feeder load.

The feeder interconnection location for Project W14 is somewhat strong, with a voltage impact ratio of 4.1 and system X/R of 1.44. The feeder interconnection location for Project W22 is weak, with a voltage impact ratio of 1.5 and system X/R of 1.0.

The feeder site for W14 in Bonarda 2101 has a step-up transformer between the site and the substation, which would have to be evaluated for any reverse flow impacts.

The feeder site for W22 in Bonarda 1102 has a recloser and a voltage regulator between the site and the substation; so interconnecting the project in this location would require evaluation for rapid reclosing into an energized island and reverse flow through the line voltage regulator.

This preliminary evaluation suggests that the feeder interconnection site for Project W22 is not likely to be low-impact. Feeder interconnection of Project W22 at that site is likely to cause overloads within the feeder and significant voltage impacts from changes in the project output, along with the potential for feeder export. Feeder interconnection of Project W14 could be low-impact. Interconnection at the given site might cause strong voltage impact. In very unusual cases, it could cause overloads of the upstream feeder and is likely to cause export from the feeder.

Substation Interconnections

As noted, the Bonarda Substation transformer has a nominal rating of 12.5 MVA. Accordingly, Project W13 could reverse flow across the substation transformer but does not have the capability alone to overload the transformer under any load conditions.

With an open 70 kV tie from Bonarda Substation to Charbono Substation, Bonarda is served essentially radially from Acolon Substation. Neither Project I71 nor Project I72 has the capability alone to overload these 70 kV lines under any load conditions. **Table 18** provides the project voltage impacts of the Bonarda Substation wholesale projects, as directly estimated at each project site using the Energynet power flow simulation.

Table 18: Bonarda Project Voltage Impacts

ID	Interconnecting Bus	Bus Number	Rated Output (kW)	Type	Quasi-dynamic Voltage Impact (ΔV, % of Nominal)
W14	Bus_F254682101_ND1300248905	706073	12,000	PV	3.9
W22	Bus_F254681102_ND1300042518	705602	10,080	PV	23.0
W13	Bus_S2546812000_12kV_MainBus_D	500513	12,000	PV	1.6
I71	Bonarda Sub 70 kV bus	34580	20,000	PV	3.2
I72	Bonarda Sub 70 kV bus	34580	20,000	PV	3.2

Source: New Power Technologies.

For the feeder interconnections of Projects W14 and W22, these results confirm first that the Project W22 site is very weak for a project of this size. A 100 percent change in the output of Project W22 would cause a quasidynamic voltage impact of 23 percent of nominal voltage at the project site under minimum daytime load conditions.

A 100 percent change in the output of Project W14 would cause a quasidynamic voltage impact of 3.9 percent of nominal voltage under minimum daytime load conditions, which might be considered acceptable. The interconnection point of the project lies downstream of the step-up transformer of the feeder. The steady-state voltage impact of a 100 percent output change of the project, after allowing for operation of the voltage regulator and transformer taps, is 3.3 percent of nominal voltage. The voltage impact of Project W13 at the substation operating bus is modest.

The voltage impacts of Projects I71 and I72 are somewhat significant, particularly for transmission-connected projects. Further, the radial path between the Acolon and Bonarda Substations is shown operating at elevated voltage under the minimum daytime load base case with no added generation. So, the addition of either Project I71 or I72 adds to a high voltage condition in the 70 kV system under those operating conditions.

DG Interconnection Groups

Considering W14 and W13 together, the two projects represent 24,000 kW of output, which would induce reverse flow in the Bonarda Substation, exceeding the normal rating of the substation transformer under minimum daytime load conditions.

Bonarda is served from Acolon at 70 kV via an essentially radial connection with an open line from Bonarda to Charbono Substation. In the minimum daytime load base case, this portion of the 70 kV system is shown operating at relatively high voltage. Projects W14 and W13 together do not result in any voltage violations within the Bonarda distribution feeders. However, they do result in mild voltage violations as well as reverse flow in the 70 kV system between Bonarda Substation and Acolon Substation.

A simultaneous 100 percent output change of W14 and W13 would cause a quasidynamic voltage change of 1.6 percent of nominal voltage at the Bonarda 12 kV bus under minimum daytime load conditions. So in this case, with the projects on different feeders, the voltage impact of each project at the point of interconnection is as great or greater than the combined voltage impact of the two projects at the substation.

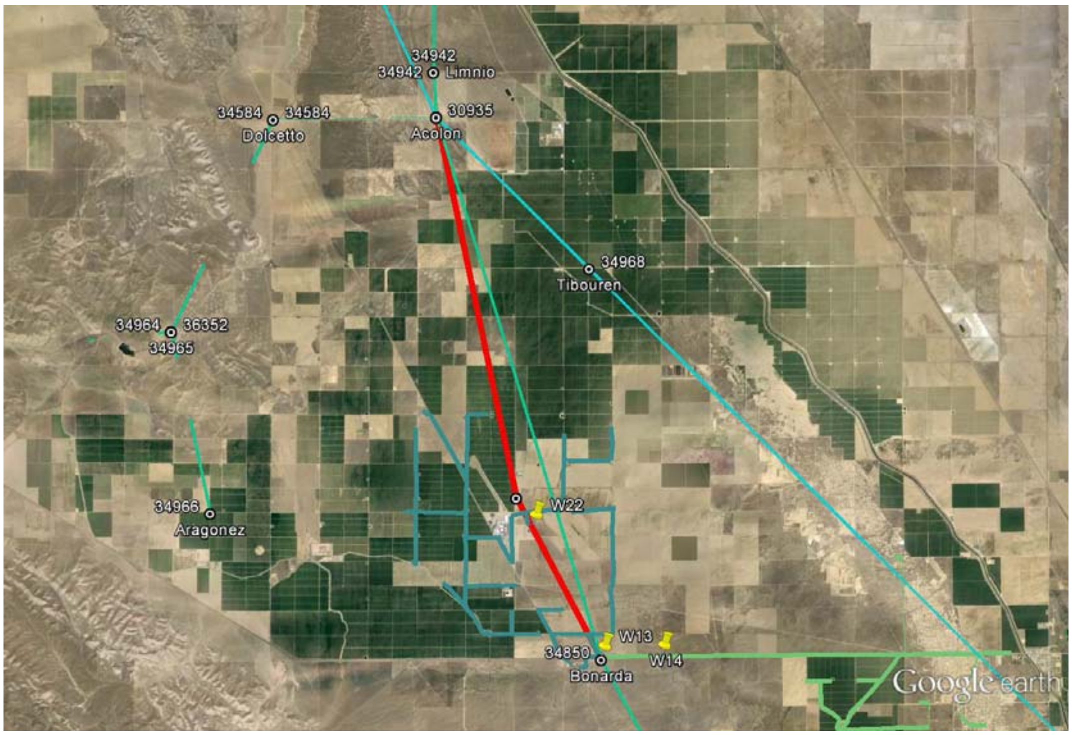
If the output of Project W22 were added to the group (presumably interconnected at some location other than Bus 705602), the resulting reverse flow at 70 kV from Bonarda to Acolon comes close to the normal rating of those lines.

As noted, either Project I71 or I72 causes an overvoltage condition at Bonarda 70 kV. The two projects together would cause significant overvoltage in the 70 kV system between Bonarda and Acolon, with 1-2 percent steady-state voltage rise at Acolon. The two projects would also overload the 70 kV lines from Bonarda to Acolon. **Figure 20** shows with red highlight the 70 kV transmission overloads between Bonarda and Acolon that would result from the combined output of the Bonarda projects under minimum daytime load conditions. This overload would be relieved under heavier loads.

The WDAT projects as a group and the California ISO projects as a group separately appear to use or exceed the capability of the 70 kV system serving Bonarda in terms of voltage and line loading. In other words, the existing 70 kV system might be able to accommodate the

WDAT projects (with no operational constraints), but with no remaining capability for the California ISO projects, or vice-versa. This is a good example of how nominally distribution interconnections can affect the viability of nominally transmission interconnections, and vice-versa.

Figure 20: Bonarda Project Impacts



Source: New Power Technologies.

Aragonez

Aragonez Substation serves two 12 kV distribution feeders, 1101 and 1102, via a 10.5 MVA 70 kV to 12 kV step-down transformer.

The PG&E WDAT queue identifies one wholesale generation project for interconnection at Aragonez Substation, at the 12 kV main bus, identified as Project W21.

Table 19 provides the project voltage impact of the Aragonez Substation wholesale project as directly estimated at each project site using the Energynet power flow simulation.

Table 19: Aragonez Project Voltage Impacts

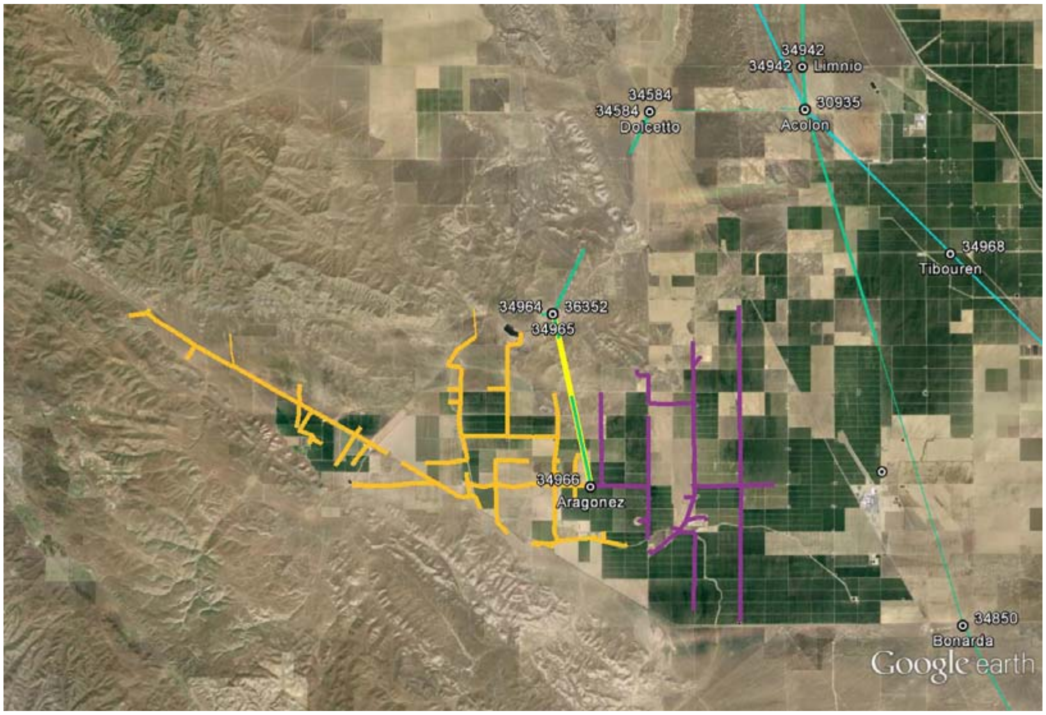
					Minimum Daytime Load
ID	Interconnecting Bus	Bus Number	Rated Output (kW)	Type	Quasi-dynamic Voltage Impact (ΔV, % of Nominal)
W21	Bus_S2520212000_12kV_MainBus	500509	10,500	PV	0.9

Source: New Power Technologies.

The quasidynamic voltage impact of Project W21 at the substation is modest. At steady-state the project does not result in any voltage violations at the substation or in the upstream 70 kV system.

Project W21 at 10,500 kW would cause reverse flow through the Aragonez Substation transformer under minimum daytime load conditions and likely most operating conditions. Reverse flow might approach the normal rating of the substation transformer under a loss of all downstream feeder load scenario but otherwise would not overload the transformer. In the upstream 70 kV system between Aragonez and Acolon, the reverse flow is limited to the incoming transmission line segment even under light load conditions, as shown as yellow highlight in **Figure 21**.

Figure 21: Aragonez Project Impacts



Source: New Power Technologies.

Tibouren

Tibouren Substation serves two distribution feeders, 1102 at 12 kV nominal and 2105 at 21 kV nominal, via two 16 MVA 70kV to 12 kV transformers. The voltage of Feeder 2105 is stepped up within the feeder.

The PG&E WDAT queue identifies six wholesale generation projects for interconnection at Tibouren Substation—three at feeder locations within Tibouren 2105, identified as Projects W16, W19, and W20, and three at 12 kV main bus at Tibouren substation, identified as Projects W15, W17, and W18.

From the California ISO queue, New Power Technologies identified no wholesale generation projects to be connected at the Tibouren Substation.

The circuit data for the Tibouren feeders identify an existing 1,000 kW generating project within Feeder 2105. This project lies in a different location in the topology than Projects W16, W19, and W20. Accordingly, New Power Technologies treated the three WDAT projects as incremental additions and incorporated the output of the existing project in the calculation of the Feeder 2105 nonexport limit.

Distribution Feeder Interconnections

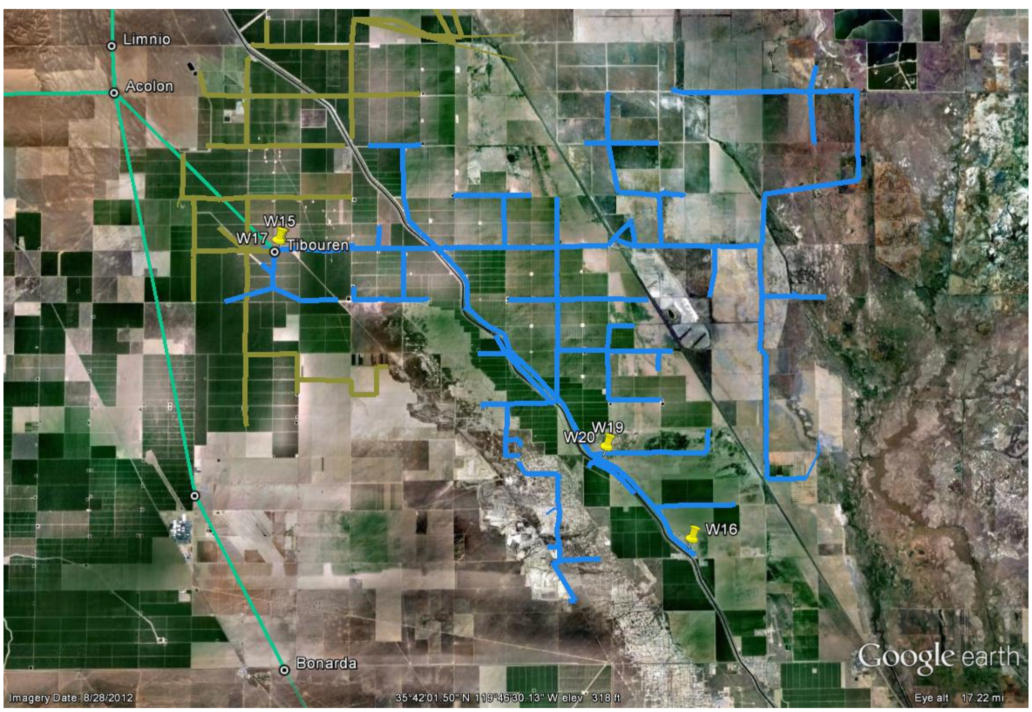
Table 20 lists the Tibouren feeder-connected WDAT project and provides details concerning the distribution network at the point of interconnection of each project. The project locations are shown in **Figure 22**, along with the two Tibouren distribution feeders in various colors and the 70 kV transmission from Acolon serving Tibouren Substation in turquoise blue. The interconnecting buses were determined by New Power Technologies as the existing network bus closest to each project, established through geocoding the project location. Project W16 is listed in the WDAT queue as under construction and is visible in **Figure 23**, along with a portion of Tibouren Feeder 2105.

Table 20: Tibouren Feeder-Connected Project Site Characteristics

ID	Interconnecting Bus	Bus Number	Rated Output (kW)	Ckt Reverse Flow Limit (MVA)	Minimum Upstream Rating (MVA)	System X/R	Utility Source SC (MVA)	Voltage Impact Ratio
W16	Bus_F254402105_swt_10	707008	1,500	1.53	11.9	1.91	11.6	7.7
W19	Bus_F254402105_ND1300019674	707139	3,000	1.53	4.6	1.69	14.9	5.0
W20	Bus_F254402105_ND1300019674	707139	3,000	1.53	4.6	1.69	14.9	5.0

Source: New Power Technologies.

Figure 22: Tibouren Interconnections



Source: New Power Technologies.

Figure 23: Project W16

Source: New Power Technologies.

Tibouren 1102 and 2105 both have multiple line voltage regulators, and Feeder 2105 has in-line voltage step-up and step-down to and from 21 kV. Thus, the existing system offers some circuit-level voltage regulation capability for generation interconnections within those feeders.

The output of Project W16 is less than the Feeder 2105 reverse flow limit. This means that W16 alone is not capable of inducing export out of Tibouren Feeder 2105 under any load conditions. Projects W19 and W20 both exceed the Feeder 2105 reverse flow limit, indicating that either project alone could induce export out of Feeder 2105 under some load conditions. The only voltage regulation point within the Feeder 2105 topology that would be subject to reverse flow from either W19 or W20 is the Feeder 2105 12 kV to 21 kV step-up transformer.

The output of each of Projects W16, W19, and W20 is under the minimum upstream line rating for the points of interconnection of each project, meaning that none of these projects individually could overload the feeder under any load conditions. While W19 and W20 lie off the same main line as W16, the most limiting upstream line rating for W19 and W20 is established by a short tap off the main line extending to the interconnection point of the projects, Bus 707139, with a lower rating. This section is visible in **Figure 24**.

Figure 24: Projects W19 and W20

Source: New Power Technologies.

Projects W16, W19, and W20 are all located at moderately strong network locations, as indicated by the voltage impact ratio evaluated at the site of each project, suggesting that the projects would induce modest voltage impacts within the feeder. The system X/R evaluated at the site of Projects W19 and W20 is slightly lower due to the lower-rated tap section noted above.

The feeder connection site for Project W16 and the site for Projects W19 and W20 in Tibouren 2105 both have a recloser between the site and the substation; so interconnecting the projects in this location would require evaluation for rapid reclosing into an energized island.

This preliminary evaluation suggests that the feeder interconnection site for Project W16 is likely to be a low-impact interconnection, with little or no chance of feeder export, equipment overloads, or significant voltage impacts. The site for Projects W19 and W20, with each project considered individually, may be low-impact but with the potential for feeder export under some load conditions and some possibility of voltage impacts.

Substation Interconnections

As noted, each Tibouren Substation transformer has a normal rating of 16 MVA. Assuming the transformers and the 12 kV operating buses are not tied, any one of Projects W15, W17, or W18 identified in the queue for interconnection at the substation 12 kV level has the potential to overload one of these transformers.

Table 21 provides the project voltage impacts of the Tibouren Substation wholesale PV projects as directly estimated at each project site using the Energynet power flow simulation under minimum daytime load conditions.

Table 21: Tibouren Project Voltage Impacts

					Minimum Daytime Load
ID	Interconnecting Bus	Bus Number	Rated Output (kW)	Type	Quasi-dynamic Voltage Impact (ΔV, % of Nominal)
W15	Bus_S2544012000_12kV_MainBus_D	500515	20,000	PV	0.1
W17	Bus_S2544012000_12kV_MainBus_D	500515	15,000	PV	0.2
W18	Bus_S2544012000_12kV_MainBus_E	500516	15,000	PV	0.2
W16	Bus_F254402105_swt_10	707008	1,500	PV	1.4
W19	Bus_F254402105_ND1300019674	707139	3,000	PV	2.4
W20	Bus_F254402105_ND1300019674	707139	3,000	PV	2.4

Source: New Power Technologies.

For Projects W16, W19, and W20, these results confirm that the interconnection points are fairly strong and changes in project output would not cause significant feeder voltage changes. A 100 percent change in the output of any of these projects would cause a quasidynamic voltage change of less than 2.5 percent of nominal voltage at the project site under minimum daytime load conditions. The estimated voltage impact of projects W19 and W20 is slightly greater due to the larger size and the lower-rated tap section at the point of interconnection. The estimated voltage impacts of Projects W15, W17, and W18 connected at Tibouren Substation are modest.

DG Interconnection Groups

Projects W16, W19, and W20 appear to be feasible feeder interconnections, though Projects W19 and W20 create the possibility of export from Feeder 2105.

As noted, the output of Project W16 is just under the Feeder 2105 circuit nonexport limit, so that project alone is not capable of causing export from Feeder 2105. Considering Project W16 grouped with either of Projects W19 or W20 yields the following. The export induced by the 3 MW project (W19 or W20) alone is exacerbated, but there are no line overloads. A simultaneous 100 percent change in the output of W16 and either of W19 or W20 causes a quasidynamic voltage change of 3 percent of nominal voltage at the Project W19/W20 site and 2.9 percent of nominal at the W16 project site, with no overvoltage conditions.

With Projects W19 and W20 together, the combined output causes a slight steady-state overvoltage condition immediately at the project site under daytime minimum load conditions. A simultaneous 100 percent change in the output of both projects causes a quasidynamic voltage change of 4.2 percent of nominal voltage at the site. Under steady-state conditions (after allowing for the operation of voltage regulator taps, and so forth), the voltage impact of a simultaneous 100 percent change in the output of both projects is 3.7 percent of nominal voltage with no overvoltage. The combined output of these projects also overloads the lower-rated tap section between the project site the main backbone of the circuit.

With all three projects W16, W19 and W20 as a group, there remains the steady-state overvoltage condition at the site of projects W19 and W20 and the overload of the lower-rated tap section at the W19 and W20 project site. However, there is no overload or overvoltage condition elsewhere in the circuit. Under these conditions, the substation transformer serving Feeder 2105 experiences reverse flow but is not overloaded. The 70 kV system serving Tibouren Substation is shown in the minimum daytime load base case as operating with slightly elevated voltage. The addition of the output of this group does not substantially affect the 70 kV voltage under steady-state conditions. The power flow direction from Acolon continues toward Tibouren due to additional 70 kV load downstream.

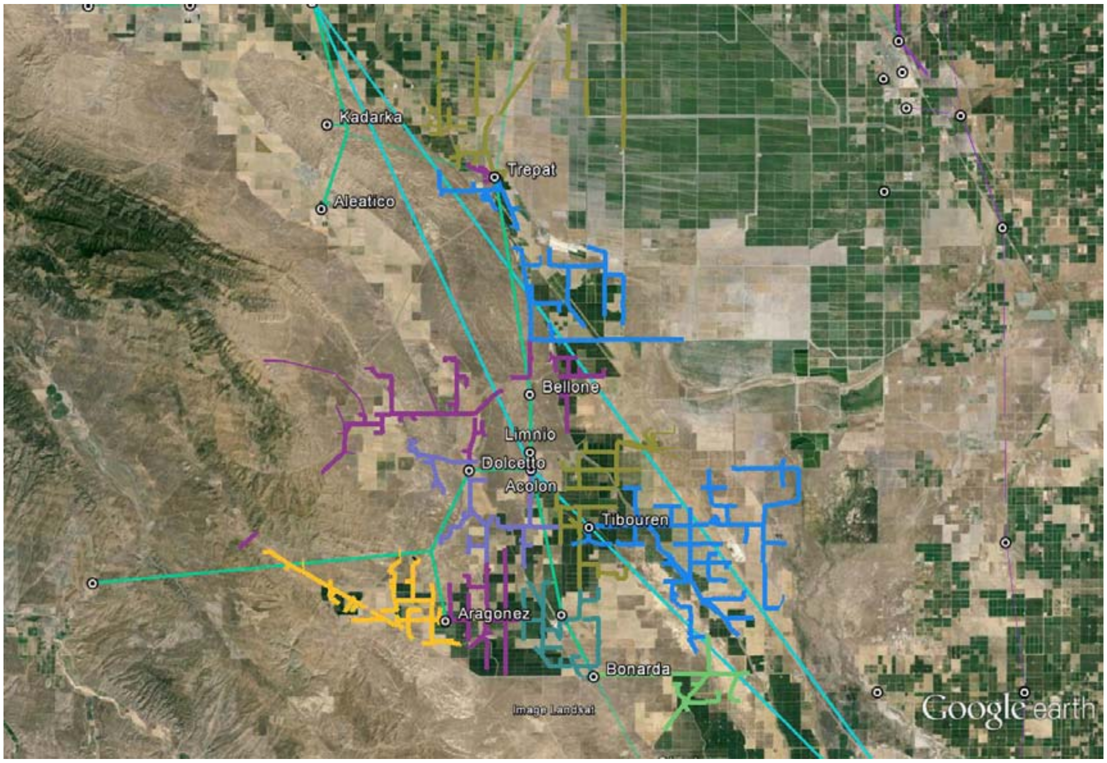
Adding Project W18 at Tibouren Substation to this group reverses the 70 kV flow from Acolon Substation but does not create any overload or new steady-state overvoltage conditions. With Project W18, the reverse flow in the substation transformer exceeds the normal rating. Adding Project W17 at Tibouren Substation induces reverse flow in the second substation transformer that exceeds its rating. The steady-state voltage at Tibouren 70 kV is further elevated, but the net change is less than 1 percent of nominal voltage. Adding Project W15 at Tibouren Substation adds to the reverse flow and overload of the substation transformer. It also adds to the reverse power flow from Tibouren now back to Acolon Substation. However, there is no large voltage impact and no overloaded transmission lines.

Thus with all of the Tibouren generation in both queues connected, representing a total of 57,500 kW, the simulated loading and voltage impacts under minimum daytime load conditions are local overload and slight overvoltage at the Project W19/W20 site, reverse flow and export from Feeder 2105, reverse flow and overload of both substation transformers, and reverse flow in the 70 kV transmission line between Tibouren and Acolon Substations.

Acolon

Acolon Substation is a major substation of the Vineyard system and is served from the 230 kV level as shown in **Figure 25**. Acolon does not directly serve any distribution feeders.

Figure 25: Acolon 70 kV



Source: New Power Technologies.

The California ISO queue identifies 12 projects representing a total of 228,000 kW for interconnection at Acolon Substation at 70 kV, referred to as Projects I57 through I70. There are also two California ISO queue projects totaling 840,000 kW identified for interconnection at Acolon Substation at 230 kV, referred to as Projects I64 and I65.

Under minimum daytime load conditions, Acolon Substation imports 61.5 MW from 230 kV to 70 kV. The substation transformer has a normal rating of 134 MVA. Accordingly, none of the Acolon 70 kV interconnections has the capability alone to induce reverse flow or overload conditions for the Acolon 230/70 kV transformer.

Table 22 provides the project voltage impacts of the Acolon Substation wholesale projects as directly estimated at each project site using the Energynet power flow simulation under minimum daytime load conditions. These projects have very modest voltage impacts.

Table 22: Acolon Substation Project Voltage Impacts

					Minimum Daytime Load
ID	Interconnecting Bus	Bus Number	Rated Output (kW)	Type	Quasi-dynamic Voltage Impact (ΔV, % of Nominal)
I57	Acolon Sub 70 kV bus	34582	20,000	PV	0.4
I58	Acolon Sub 70 kV bus	34582	20,000	PV	0.4
I59	Acolon Sub 70 kV bus	34582	20,000	PV	0.4
I60	Acolon Sub 70 kV bus	34582	20,000	PV	0.4
I61	Acolon Sub 70 kV bus	34582	20,000	PV	0.4
I62	Acolon Sub 70 kV bus	34582	20,000	PV	0.4
I63	Acolon Sub 70 kV bus	34582	20,000	PV	0.4
I66	Acolon Sub 70 kV bus	34582	20,000	PV	0.4
I67	Acolon Sub 70 kV bus	34582	20,000	PV	0.4
I68	Acolon Sub 70 kV bus	34582	8,000	PV	0.2
I69	Acolon Sub 70 kV bus	34582	15,000	PV	0.3
I70	Acolon Sub 70 kV bus	34582	25,000	PV	0.5
I64	Acolon Sub 230 kV bus	30935	300,000	PV	1.3
I65	Acolon Sub 230 kV bus	30935	540,000	ST	1.6

Source: New Power Technologies.

Acolon 70 kV Operational Subnetwork

With open 70 kV ties separating Bonarda Substation from Charbono Substation and separating Trepat Substation from Kadarka Substation, Trepat, Dolcetto, Bonarda, Aragonez, and Tibouren Substations and the distribution feeders are electrically related to one another under Acolon 70 kV and distinct from the other distribution feeders in Kadarka DPA (Aleatico and Kadarka) and Bonarda DPA (Charbono). Accordingly, New Power Technologies considers the wholesale PV interconnections at these substations and the feeders as a group under Acolon 70kV for evaluation. The subnetwork under Acolon 70 kV is shown in **Figure 25**. The distribution feeders under the substations are shown in various colors. The 70 kV network joining the substations is shown in turquoise blue, and the 230 kV source for Acolon is shown in dark turquoise.

Within Acolon, there are 17 proposed interconnections in the WDAT and California ISO queues nominally associated with Trepat, Dolcetto, Bonarda, or Tibouren Substation. Together, these represent 223,580 kW of total output. The individual and substation group-level impacts of these projects are discussed above in connection with their individual substations.

There are also 12 California ISO queue projects representing a total of 228,000 kW for interconnection at Acolon Substation at 70 kV and two California ISO queue projects totaling 840,000 kW identified for interconnection at Acolon Substation at 230 kV. The impacts of these projects are discussed in connection with Acolon Substation above.

Considering first the wholesale PV interconnections related to the substations within Acolon 70 kV, as stated above, Trepat Substation projects as a group affect the radial 70 kV line from Acolon to Trepat via Bellone. Project W22, a large project in a weak location, seems to be the most problematic interconnection within Acolon 70 kV. If New Power Technologies omits that project and assumes Projects W9 and W10 are connected at Trepat Substation, these projects elevate the voltage between Trepat and Acolon and cause a slight overload between Trepat and Bellone Substations. However, closing the open 70 kV tie between Trepat and Hondarribi relieves the overload entirely and nearly relieves the overvoltage.

Bonarda Substation projects affect the radial 70 kV line between Bonarda and Acolon. With Projects W13 and W14 at Bonarda, there is reverse flow to Acolon and high voltage at Bonarda 70 kV. However, closing the open 70 kV tie between Bonarda and Charbono relieves the high-voltage condition. Projects I70 and I71 at Bonarda Substation result in somewhat elevated 70 kV voltage at Bonarda and overload of the relatively lightly rated line from Acolon to Bonarda.

The project at Aragonez Substation affects the line between Aragonez and Acolon, though there is other served load on other substations and reverse flow from Aragonez is contained. Project W21 at Aragonez reduces the power flow from Acolon via Dolcetto, but it does not result in any overload or overvoltage conditions.

The projects at Tibouren Substation affect the radial line between Tibouren and Acolon. W16, W19, W20, and W18 at Tibouren together reverse the flow from Tibouren to Acolon. Adding W15 and W17 further reverses the 70 kV flow but does not result in any overvoltage or overload conditions.

In total, these projects represent 172 MW of total output, which is enough to reverse the flow at the Acolon 230/70 kV transformer under daytime minimum load conditions. Several distribution substation transformers see reverse flow exceeding the normal ratings. However, high voltage conditions within the distribution feeders that could affect other customers are limited to near some generation projects. There are also some local overloads, but only one lightly rated transmission path is overloaded under daytime minimum load conditions. No project can influence local voltage by more than 4 percent of nominal voltage under minimum daytime load conditions.

Closing some 70 kV ties to increase the networked characteristic of the system seems to improve the ability of the system to accommodate additional generation.

Under these conditions, reverse flow at Acolon Substation from 70 kV to 230 kV is about 50 MW. So, conceivably the system under Acolon 70 kV could also accommodate some of the California ISO queue generation at 70 kV. Once the 70 kV lines to the load-serving substations experience reverse flow, the proposed interconnections at the Acolon Substation 70 kV bus are, in effect, competing for the same system capacity.

Charbono

Charbono Substation is nominally part of Bonarda DPA with Bonarda, Tibouren, and Aragonez Substations and their distribution feeders. With an open 70 kV tie between Bonarda and Charbono, Charbono is not served from Acolon and is electrically distinct from these other substations. Charbono serves two 12 kV distribution feeders, 1102 and 1103.

From the California ISO queue, New Power Technologies identified one project, I73, associated with Charbono Substation. New Power Technologies modeled Project I73 as connected to the Charbono Substation 70 kV bus.

Table 23 provides the project voltage impact of the Charbono Substation wholesale project as directly estimated at each project site, using the Energynet power flow simulation under minimum daytime load conditions.

Table 23: Charbono Project Voltage Impacts

					Minimum Daytime Load
ID	Interconnecting Bus	Bus Number	Rated Output (kW)	Type	Quasi-dynamic Voltage Impact (ΔV, % of Nominal)
I73	Charbono Sub 70 kV bus	34852	75,000	PV	16.1

Source: New Power Technologies.

With the open tie to Bonarda, Charbono is served essentially radially at 70 kV. New Power Technologies estimates the incoming 70 kV line serves only about 4.4 MW under minimum daytime load conditions, and its normal rating is only 31 MVA. Project I 73 is one of the larger 70 kV interconnections. So, Project I73 has relatively significant voltage impacts. It also would cause reverse flow exceeding the line rating at 70 kV and high voltage within the 70 kV system.

Closing the 70 kV tie to Bonarda relieves the 70 kV overload and overvoltage. However, overvoltage at Charbono 70 kV persists, and the 70 kV line to Bonarda and continuing to Acolon is overloaded. In this network configuration, Project I73 would become part of the group under Acolon 70 kV discussed above with direct interaction with the Bonarda Substation projects.

Grasa

Grasa Substation serves two 12 kV distribution feeders, 1102 and 1103, via a single 17.63 MVA 70 kV to 12 kV transformer. The PG&E Renewable Auction Mechanism (RAM) maps identify two additional Grasa feeders, 1106 and 1107. These may have been added after April 2012, the date of the power system data for this project.

The PG&E WDAT queue identifies five wholesale generation projects for interconnection at Grasa Substation—Projects W29, W30, W31, W32, and W33. There is an additional 10 MW project nominally identified with Grasa Substation in the WDAT queue; however, additional data provided by PG&E indicate that this project is in a different location.

The interconnection schemes of W29 and W33 are not specified in the WDAT queue or in additional information provided by PG&E; the others are expected to tie directly to Grasa Substation at 12 kV. In the absence of any information on the location of Project W33, New Power Technologies evaluated it as connected directly to Grasa Substation at 12 kV. The other geocoded project locations are shown as pushpins in **Figure 26**, along with the two Grasa distribution feeders as colored lines.

Figure 26: Grasa Interconnections

Source: New Power Technologies.

Google Earth shows a large PV project that may be connected to Grasa Substation. This project is shown in **Figure 27** with portions of Grasa Feeder 1103 running past the site. The site is near Project W29, which is shown as under construction in the WDAT queue. Based on its size, the visible project is roughly 8.2 MW, so it is considerably smaller than Project W29 as listed in the queue. No existing generation project in this location appears in the circuit data available to New Power Technologies for the Grasa Substation and related circuits or as a generation unit at the Grasa Substation in the regional transmission data sets. From the layout of the circuits in the PG&E Renewable Auction Mechanism maps, it would be reasonable to infer that Feeders 1106 and 1107 are related to the interconnection of this project, possibly as dedicated feeders.

For this study New Power Technologies evaluated Project W29 as a 20 MW project consistent with the characterization in the WDAT queue, with feeder-connected and substation-connected variants, as discussed below. New Power Technologies also evaluated W29 as an 8.2 MW feeder-connected project within Grasa Feeder 1103, consistent with the project that is visible in **Figure 27**.

Figure 27: PV Project Near Grasa Substation

Source: New Power Technologies.

From the California ISO queue, New Power Technologies identified two wholesale generation projects at the Grasa Substation, both to be connected at the 70 kV bus. The California ISO projects together represent 37.9 MW of capacity. All of these wholesale projects are PV projects.

Feeder Interconnections

While none of the WDAT projects attributed to Grasa Substation is identified as distribution feeder interconnections in the queue, New Power Technologies evaluated alternate feeder interconnections for four of the Grasa WDAT projects—W29 and W30 in Feeder 1103 and W31 and W32 in Feeder 1102. The locations of the projects are shown in **Figure 26**. In each case, the alternate interconnection point for each project was the distribution bus nearest the geocoded location of the generating project.

Table 24 lists the distribution feeder connection alternate sites for the four Grasa WDAT projects and provides details concerning the distribution network at the point of interconnection for each project.

Table 24: Grasa Feeder-Connected Project Site Characteristics

ID	Interconnecting Bus	Bus Number	Rated Output (kW)	Ckt Reverse Flow Limit (MVA)	Minimum Upstream Rating (MVA)	System X/R	Utility Source SC (MVA)	Voltage Impact Ratio
W29 (alt)	Bus_F253151103_struc_285	710618	20,000	2.9	5.6	1.56	60.4	3.0
W29 (alt)	Bus_F253151103_struc_285	710618	8,200	2.9	5.6	1.56	60.4	7.4
W30 (alt)	Bus_F253151103_struc_126	710529	12,000	2.9	2.6	0.66	24.8	2.1
W31 (alt)	Bus_F253151102_struc_149	710144	10,000	2.4	9.1	2.12	289.3	28.9
W32 (alt)	Bus_F253151102_struc_149	710144	10,000	2.4	9.1	2.12	289.3	28.9

Source: New Power Technologies.

Grasa 1102 and 1103 both have line voltage regulators, which provide some circuit-level voltage regulation capability to accommodate feeder-connected generation.

The circuit reverse flow limit indicates that the feeder-connected alternate interconnections for W29, W30, W31, and W32 could induce export out of the respective feeders under minimum daytime load conditions. W29, represented as an 8.2 MW project, still has the ability to induce export from Feeder 1103 under some load conditions.

W29 and W30 connected at the Feeder 1103 sites would exceed the minimum line rating upstream of the points of interconnection, introducing the possibility of an overload of upstream components. W29, as an 8.2 MW project, still exceeds the minimum upstream line rating for that location. W31 and W32 connected at the Feeder 1102 sites also exceed the minimum upstream line rating for the points of interconnection, in theory introducing the possibility of an overload of upstream components. However, the output of each of these projects is very near the minimum upstream rating, meaning the load on those lines would approach the normal rating only under extremely low feeder load conditions.

The alternate feeder connection sites for W29 and W30 are both relatively weak network locations, with the voltage impact ratios for both projects under 5 and, in the case of Project W30, a system X/R value under 1.0. Thus, interconnecting those projects at these feeder locations is more likely to cause significant voltage fluctuations within the feeder due to variation in output. W29, as an 8.2 MW project, has a somewhat more favorable voltage impact ratio of 7.4, suggesting a reduced likelihood of significant voltage fluctuations in the feeder due to variation in output for the project. The distribution feeder alternate site for W31 and W32 is a strong location, with a voltage impact ratio well above 5 for either project; so interconnecting either of these projects at this location is unlikely to cause significant voltage fluctuation due to variation in output for the project.

The feeder connection sites for W30, W31, and W32 have no reclosers or voltage regulators upstream. Accordingly, interconnecting these projects in these locations would introduce no concerns about rapid reclosing into an energized island or reverse flow through line voltage regulators. The site for W29 has a recloser upstream but no voltage regulator.

On the basis of this preliminary evaluation, the distribution feeder interconnection site for W31 or W32 appears to be a relatively low-impact interconnection apart from the potential for feeder export and the remote possibility of an overload under some low-load conditions. The distribution feeder alternate interconnections for W29 and W30 are probably not low-impact interconnections. Both projects in these locations introduce the potential for overloads of upstream components and potential unacceptable voltage fluctuations from changes in output due to the low voltage impact ratios for those projects in those locations. Both projects also have the potential to induce feeder export. The feeder interconnection of W29 as a smaller 8.2 MW project still does not appear to be low-impact. This interconnection retains the possibility overload, as well as feeder export. The voltage impact ratio is somewhat higher, but system voltage fluctuations remain a possibility.

Table 25 provides the project voltage impacts of the Grasa Substation wholesale projects at the alternate distribution feeder interconnection sites as directly estimated at each project site using the Energynet power flow simulation.

Table 25: Grasa Feeder-Connected Project Voltage Impacts

					Minimum Daytime Load
ID	**Interconnecting Bus**	**Bus Number**	**Rated Output (kW)**	**Type**	**Quasi-dynamic Voltage Impact (ΔV, % of Nominal)**
W29 (alt)	Bus_F253151103_struc_285	710618	20,000	PV	9.2
W29 (alt)	Bus_F253151103_struc_285	710618	8,200	PV	5.0
W30 (alt)	Bus_F253151103_struc_126	710529	12,000	PV	21.7
W31 (alt)	Bus_F253151102_struc_149	710144	10,000	PV	1.5
W32 (alt)	Bus_F253151102_struc_149	710144	10,000	PV	1.5

Source: New Power Technologies.

These results confirm the outcomes suggested by the voltage impact ratios described in **Table 22.** A 100 percent output change of either W31 or W32 has relatively little network voltage impact due to the relative strength of the system at that location. Each project has quasidynamic voltage impact equal to a change in voltage of well under 3 percent of nominal under either peak load or minimum daytime load conditions. For Project W29 at 20 MW, with a voltage impact ratio of 3, the quasidynamic voltage impact is more than 9 percent of nominal voltage. For Project W29 at 8.2 MW, a 100 percent change in project output still causes a system voltage change of 5 percent of nominal under minimum daytime load conditions. For W30, with a voltage impact ratio of 2.1, the quasidynamic voltage impact is a voltage change of more than 20 percent of nominal.

Substation Interconnections

As noted, Grasa Substation has a 17.63 MVA 70 kV to 12 kV transformer. Accordingly, as substation connections, none of the Grasa WDAT projects except W29 as a 20 MW project has the ability, individually, to overload the substation transformer under any load conditions.

The two California ISO projects proposed for interconnection at Grasa 70 kV do not affect the Grasa transformer. Grasa Substation is served radially at 70 kV via a line with a 22 MVA normal rating. Thus, neither California ISO project has the ability to overload the incoming 70 kV line under any load conditions.

Table 26 provides the project voltage impacts of the Grasa WDAT projects as interconnected at the substation operating bus and the Grasa California ISO projects as directly estimated using the Energynet power flow simulation. These results indicate that the voltage impacts of these projects individually are small. As with the projects at the Gamay Substation, where Gamay Substation wholesale projects could conceivably be connected out on a distribution feeder, such as with W31 or W32, characterizing these particular projects at the 12 kV substation bus apparently does not magnify voltage impact.

Table 26: Grasa Substation-Connected Projects Voltage Impacts

					Minimum Daytime Load
ID	Interconnecting Bus	Bus Number	Rated Output (kW)	Type	Quasi-dynamic Voltage Impact (ΔV, % of Nominal)
W29	Bus_S2531512000_12kV_MainBus_D	500525	20,000	PV	0.8
W30	Bus_S2531512000_12kV_MainBus_D	500525	12,000	PV	0.6
W31	Bus_S2531512000_12kV_MainBus_D	500525	10,000	PV	0.6
W32	Bus_S2531512000_12kV_MainBus_D	500525	10,000	PV	0.6
W33	Bus_S2531512000_12kV_MainBus_D	500525	1,500	PV	0.1
I9	Grasa Sub 70 kV bus	34470	20,000	PV	1.1
I10	Grasa Sub 70 kV bus	34470	17,900	PV	1.0

Source: New Power Technologies.

DG Interconnection Groups

Projects W31 and W32 appear to be feasible feeder interconnections within Grasa 1102. Evaluating the two projects together, for example, as interconnected at the same point of interconnection at Bus 710144, yields the following results. These two projects, representing 20 MW together, would far exceed the 2.5 MW nonexport limit of load of Feeder 1102 under minimum daytime load conditions, resulting in a high likelihood of export from the feeder. The two projects together would also exceed the minimum upstream line rating applicable to that site, introducing the possibility of an overload under some feeder load conditions. The effective voltage impact ratio for the two projects at that location is 14.5, suggesting the voltage impact of coincident output changes of the group may not be significant. In fact, as seen in the Energynet simulation, the two projects increase the steady-state voltage at the project site by 2.3 percent of nominal voltage under minimum daytime load conditions. A simultaneous 100 percent output change of the two projects would cause a quasidynamic voltage change at the project site of 2.3 percent of nominal voltage under minimum daytime load conditions, consistent with the relatively high effective voltage impact ratio of the interconnection.

So, one reasonable group configuration of the Grasa WDAT projects for analytical purposes is with Projects W29, W30, and W33 connected at the respective 12 kV substation operating buses (or via dedicated feeders), and W31 and W32 connected at Bus 710144 in Grasa Feeder 1102.

In this configuration, all five WDAT projects effectively influence the single 17.63 MVA transformer at Grasa Substation. These projects together would cause 49 MW of reverse flow through the Grasa Substation transformer under minimum daytime load conditions, exceeding the transformer rating.

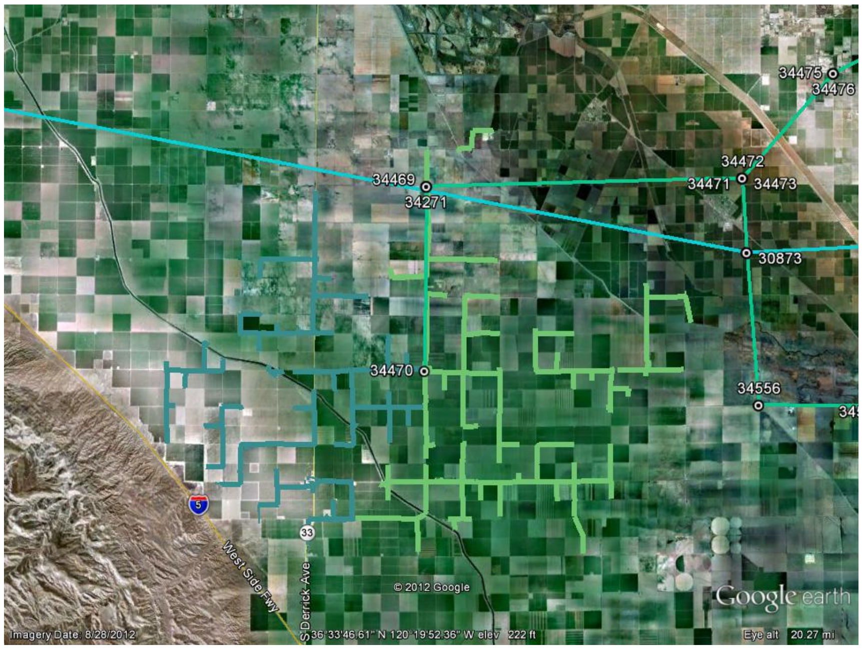
This reverse flow also exceeds the rating of the incoming 70 kV line serving Grasa substation. Adding the combined 37.9 MW output of the two California ISO wholesale projects proposed for the Grasa 70 kV bus, I9 and I10, simply exacerbates the reverse flow and overload of the 70 kV transmission system serving Grasa substation, extending the overloaded lines toward Hron substation.

In terms of voltage impacts, in this configuration the combined output of this group of five WDAT projects has little impact on the steady-state voltage at Grasa 12 kV or 70 kV or in the 70 kV transmission system between Grasa and Hron, with no more than 1.1 percent voltage change at any of those buses. The quasidynamic voltage impact of a simultaneous 100 percent output change of this group of projects is also small.

Figure 28 shows the power delivery system around Grasa Substation. The regional transmission lines are again shown as dark turquoise (230 kV) and turquoise (70 kV), with the other colors representing the distribution feeders served from Grasa, which is marked as bus 34470. **Figure 29** illustrates the loading impacts of the WDAT projects identified for

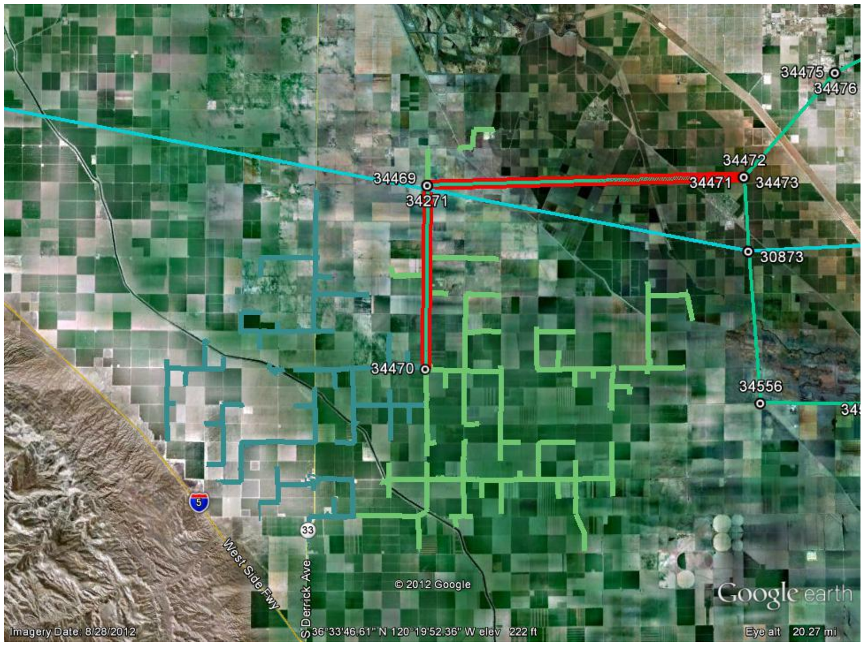
Grasa Substation, with overloads as red highlight. **Figure 30** shows as red highlight the additional overloads resulting from the Grasa interconnections in the California ISO queue.

Figure 28: Grasa Distribution and Transmission



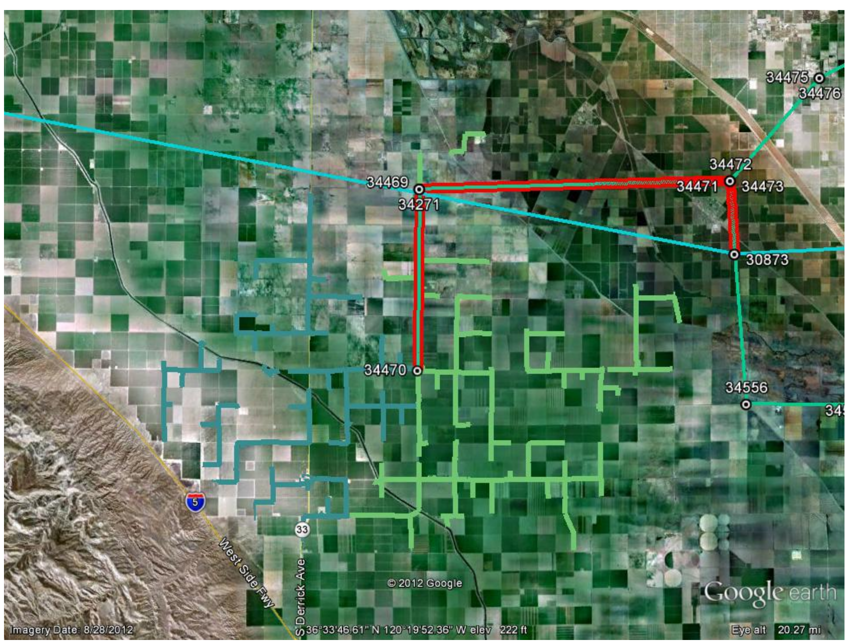
Source: New Power Technologies.

Figure 29: Transmission Overloads From Grasa WDAT Projects



Source: New Power Technologies.

Figure 30: Transmission Overloads From Grasa WDAT and California ISO Projects



Source: New Power Technologies.

The Energynet power system model integrating transmission and distribution used in this study reveals a particularly interesting group example—Project W30 grouped with Project I9. WDAT Project W30 might be viewed as a workable interconnection at the Grasa 12 kV bus—that is, with acceptable voltage and power flow impacts on the distribution feeders, and acceptable loading impacts on the Grasa Substation transformer. Separately, California ISO Project I9 might be viewed as a workable interconnection at the Grasa 70 kV bus. Neither of these projects causes any overloads or voltage violations. However, these two projects together, simulated in the Energynet model under minimum daytime load conditions, would overload two sections of 70 kV transmission line serving Grasa Substation, as shown in **Figure 29**, and cause voltage violations at two 70 kV transmission substations.

This example clearly shows that nominal distribution interconnections can affect nominal transmission interconnections, and vice-versa, and evaluating interconnections in the two systems together in a fully coupled simulation provides additional insights. It also shows that projects in the WDAT and California ISO queues can have compounding impacts, and these queues need to be coordinated.

Sangiovese

Sangiovese Substation serves three 12 kV distribution feeders, 1101 1102, and 1104, via a 17.6 MVA 70 kV to 12 kV transformer. The PG&E WDAT queue identifies five wholesale generation projects for interconnection at Sangiovese Substation—four at feeder locations within Sangiovese 1101, identified as Projects W42 through W45, and one specifically at the Sangiovese 12 kV main bus identified as Project W46. The WDAT projects together represent 62,900 kW. Given the sizes of Projects W43 and W44, New Power Technologies also evaluated alternative interconnections for W43 and W44 at the Sangiovese 12 kV main bus, indicative of dedicated feeder interconnections.

Project W43 is shown in the WDAT queue as in service, and the project is visible along with a portion of Feeder 1101 in **Figure 31**. While the visible size of the project suggests total output of around 13 MW, New Power Technologies evaluated W43 at 20 MW, as it is described in the WDAT queue.

Figure 31: PV Project Near Sangiovese Substation

Source: New Power Technologies.

From the California ISO queue, New Power Technologies identified five wholesale generation projects at the Sangiovese Substation, all to be connected at the 70 kV bus. Together, these five projects represent 119,900 kW. These are identified as I40 through I44.

Distribution Feeder Interconnections

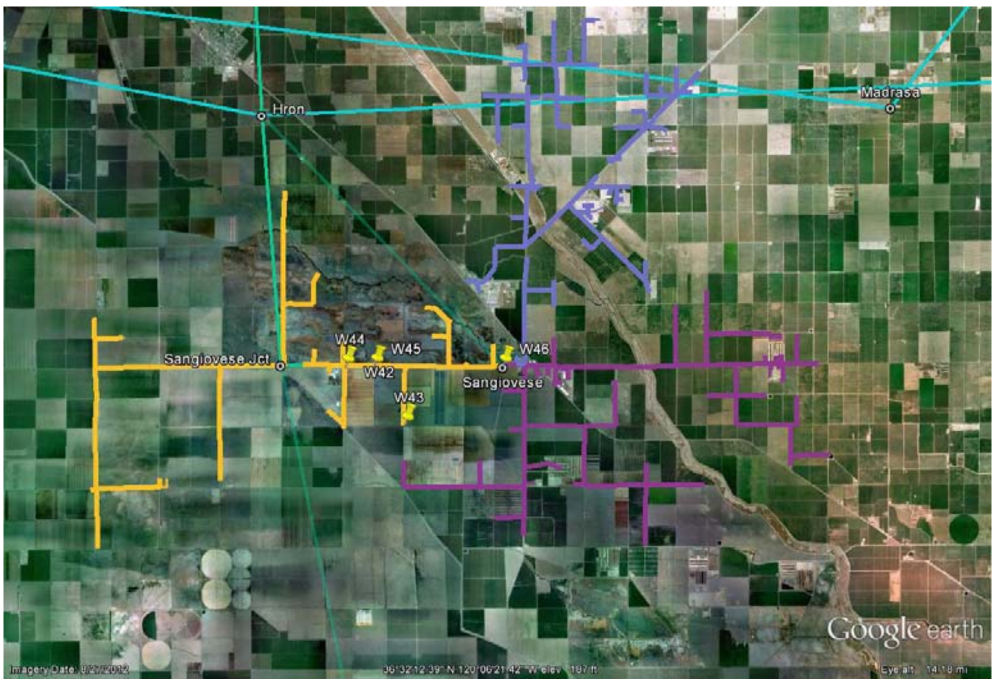
Table 27 lists the four Sangiovese feeder-connected WDAT projects and provides details concerning the distribution network at the point of interconnection for each project. In each case, the interconnecting bus was determined by New Power Technologies as the existing network bus closest to the project, established through geocoding the project location. The project locations are shown in **Figure 32** along with the Sangiovese distribution feeders in various colors and the 70 kV transmission serving Sangiovese Substation in turquoise blue.

Table 27: Sangiovese Feeder-Connected Project Site Characteristics

ID	Interconnecting Bus	Bus Number	Rated Output (kW)	Ckt Reverse Flow Limit (MVA)	Minimum Upstream Rating (MVA)	System X/R	Utility Source SC (MVA)	Voltage Impact Ratio
W42	Bus_F253661101_cap_1	724018	1,450	1.15	4.6	1.61	56.0	38.6
W43	Bus_F253661101_struc_29	724076	20,000	1.15	2.6	0.60	26.5	1.3
W44	Bus_F253661101_struc_77	724062	20,000	1.15	2.6	1.27	41.6	2.1
W45	Bus_F253661101_cap_1	724018	1,450	1.15	4.6	1.61	56.0	38.6

Source: New Power Technologies.

Figure 32: Sangiovese Interconnections



Source: New Power Technologies.

Sangiovese 1101 and 1104 have boosters or line voltage regulators. Thus, the existing system offers some circuit-level voltage regulation capability for interconnections on Feeder 1101.

The circuit reverse flow limit for Feeder 1101 indicates that any of these projects has the potential to induce export out of Sangiovese 1101 under minimum daytime load conditions. Projects W42 and W45 are sized very near the limit, however, and would likely not induce export under many operating conditions.

Projects W42 and W45 are also well under the minimum upstream line ratings for the point of interconnection, meaning neither project alone could cause an overload in the feeder under any load conditions. Projects W43 and W44 are well over the minimum upstream line ratings for the points of interconnection, creating the possibility of an overload.

Projects W42 and W45 are also located at relatively strong network locations, as indicated by the voltage impact ratios of 38.6. Projects W43 and W44 are in much weaker locations in absolute terms, as indicated by the system X/R at each point. Both projects are also much larger than W42 or W45, resulting in voltage impact ratios well under 5.0.

The feeder connection site for Projects W42 and W45 and the sites for W43 and W44 have no reclosers or voltage regulators upstream. Accordingly, interconnecting these projects in these locations would introduce no concerns about rapid reclosing into an energized island or reverse flow through line voltage regulators.

This preliminary evaluation suggests that feeder interconnection sites for W43 and W44 could present challenges in terms of reverse flow, loading, and voltage impacts. On the other hand, the feeder interconnection locations for W42 and W45 may be fairly low-impact, with impacts potentially limited to occasional reverse flow and circuit export.

Substation Interconnections

As noted, the Sangiovese Substation transformer has a normal rating of 17.6 MVA. Accordingly, Project W46 or either W43 or W44 connected at the 12 kV bus of the substation has the theoretical potential to overload the transformer. However, under minimum daytime load conditions, New Power Technologies estimates that Sangiovese Substation would serve about 5.1 MW; so under minimal loading conditions, the output of any one of these 20 MW projects would cause reverse flow within the substation but within the normal rating of the transformer.

The incoming 70 kV line serving Sangiovese is rated at 36 MVA, so none of the WDAT projects has the capability to overload this line. One of the California ISO projects, I40, could theoretically overload this line but only under a full loss of downstream load condition.

Table 28 provides the project voltage impacts of the Sangiovese Substation wholesale projects, as directly estimated at each project site using the Energynet power flow simulation.

Table 28: Sangiovese Project Voltage Impacts

					Minimum Daytime Load
ID	Interconnecting Bus	Bus Number	Rated Output (kW)	Type	Quasi-dynamic Voltage Impact (ΔV, % of Nominal)
W42	Bus_F253661101_cap_1	724018	1,450	PV	1.0
W43	Bus_F253661101_struc_29	724076	20,000	PV	31.1
W43 (alt)	Bus_S2536612000_12kV_MainBus_D	500540	20,000	PV	1.0
W44	Bus_F253661101_struc_77	724062	20,000	PV	14.3
W44 (alt)	Bus_S2536612000_12kV_MainBus_D	500540	20,000	PV	1.0
W45	Bus_F253661101_cap_1	724018	1,450	PV	1.0
W46	Bus_S2536612000_12kV_MainBus_D	500540	20,000	PV	1.0
I40	Sangiovese Sub 70 kV bus	34564	40,000	PV	2.5
I41	Sangiovese Sub 70 kV bus	34564	19,900	PV	1.3
I42	Sangiovese Sub 70 kV bus	34564	20,000	PV	1.3
I43	Sangiovese Sub 70 kV bus	34564	20,000	PV	1.3
I44	Sangiovese Sub 70 kV bus	34564	20,000	PV	1.3

Source: New Power Technologies.

For the feeder interconnections of Projects W42 through W45, these results confirm the outcomes suggested by the voltage impact ratios depicted in **Table 25**. A 100 percent output change from either W42 or W45 has relatively little voltage impact due to the relative strength of the system at the location. A 100 percent output change of either of these projects would cause a quasidynamic voltage change equal to well under 3 percent of nominal voltage under minimum daytime load conditions.

In the case of feeder interconnections of Projects W43 or W44, a 100 percent output change of either project has a very significant quasidynamic voltage impact.

Project W46 and the substation-connected alternates for Projects W43 and W44 at the Sangiovese Substation main bus have modest voltage impacts.

If Project W43 is in service at an output level of 20 MW, it has the theoretical capability to overload the 17.6 MVA Sangiovese Substation transformer, as noted. New Power Technologies estimates that in simulation under minimum daytime load conditions, W20 would induce reverse flow of about 14.9 MW across the Sangiovese Substation. The 70 kV system serving Sangiovese Substation is shown in the minimum daytime load base case (with no added generation) as operating at slight overvoltage. Thus, while the incremental voltage impact of Project W43 with the alternate interconnection at the Sangiovese 12 kV main bus is small, the addition of Project W43 at 20 MW results in a voltage violation at the Sangiovese 70 kV bus.

Of the California ISO queue projects, all have modest voltage impacts at the point of interconnection. The largest, Project I40, has a quasidynamic voltage impact of less than 3 percent of nominal voltage.

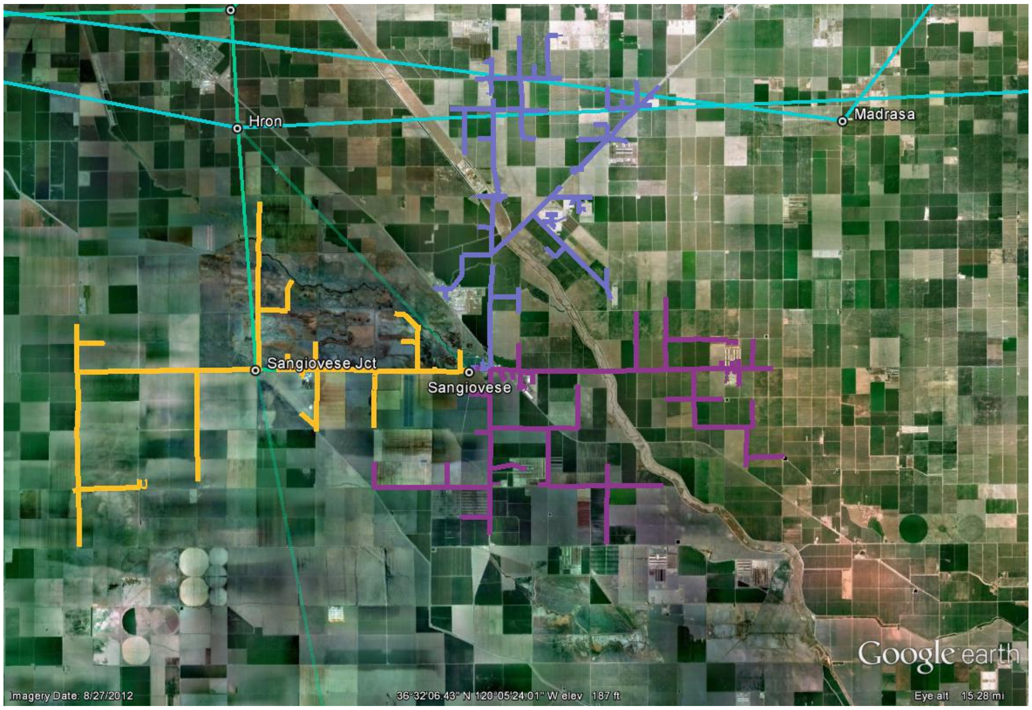
DG Interconnection Groups

Projects W42 and W45 appear to be feasible feeder interconnections. Together, a 100 percent simultaneous output change causes a quasidynamic voltage change of 2.1 percent of nominal voltage at the point of interconnection under minimum daytime load conditions, which is arguably still acceptable. The two projects together also do not exceed the minimum upstream line rating for the point of interconnection, eliminating the possibility of an overload. The two projects at 2.9 MW total output would exceed the nonexport limit for Feeder 1101 and could cause export from the circuit under some load conditions. In the Sangiovese 1101 topology, the only voltage regulation point that would be subject to reverse flow in such an event is the substation transformer itself.

Feeder-connected Projects W42 and W45, grouped with substation-connected Project W43 (or any of the 20 MW projects proposed for the Sangiovese substation 12 kV bus), result in 17.8 MW of reverse flow through the substation transformer under minimum daytime load conditions, which is right at the normal rating of the transformer. This also causes a slight further increase in steady-state voltage at Sangiovese 70 kV. In other words, given a group composed of Projects W42, W45, and W43, any additional WDAT projects at Sangiovese 12 kV would potentially overload the substation transformer under some load conditions.

Figure 33 shows the Vineyard power delivery system around Sangiovese Substation. The regional transmission lines are again shown as dark turquoise (230 kV) and turquoise (70 kV), with the other colors representing the distribution feeders served from Sangiovese.

Figure 33: Sangiovese Distribution and Transmission



Source: New Power Technologies.

Like Grasa Substation, Sangiovese is served radially. Consequently, any reverse flow through the transformer also reverses the flow in the incoming 70 kV transmission line.

Apart from the Sangiovese Substation transformer constraint, the incoming 70 kV transmission line serving Sangiovese has about 18 MVA of its normal rated capacity remaining under minimum daytime load conditions with the W42/W45/W43 group operating. Accordingly, any additional WDAT projects at Sangiovese 12 kV would potentially overload the incoming 70 kV line under some load conditions.

The 70 kV line from Hron to Sangiovese Junction has a slightly higher rating, so a group comprising feeder-connected W42 and W45 and substation-connected W43 and W46 results in no overloads or voltage violations beyond Sangiovese Junction.

In terms of voltage impacts in this configuration, the combined output of this group of four WDAT projects has little impact on the steady-state voltage at Sangiovese 12 kV or 70 kV or in the 70 kV transmission system between Sangiovese and Hron, with no more than 1.4 percent voltage change at any of those buses. The quasidynamic voltage impact of a simultaneous 100 percent output change of this group of projects is also small.

Projects proposed for interconnection at Sangiovese 12 kV in the WDAT queue and projects proposed for interconnection at Sangiovese 70 kV in the California ISO queue compete directly with each other for this capacity once the Sangiovese load is displaced. In other words, a W42/W45/W43/W46 group representing 42.9 MW of total output would essentially fully use the available capability of the Hron-Sangiovese 70 kV path under daytime minimum load conditions, effectively precluding any of the California ISO queue projects proposed for Sangiovese 70 kV.

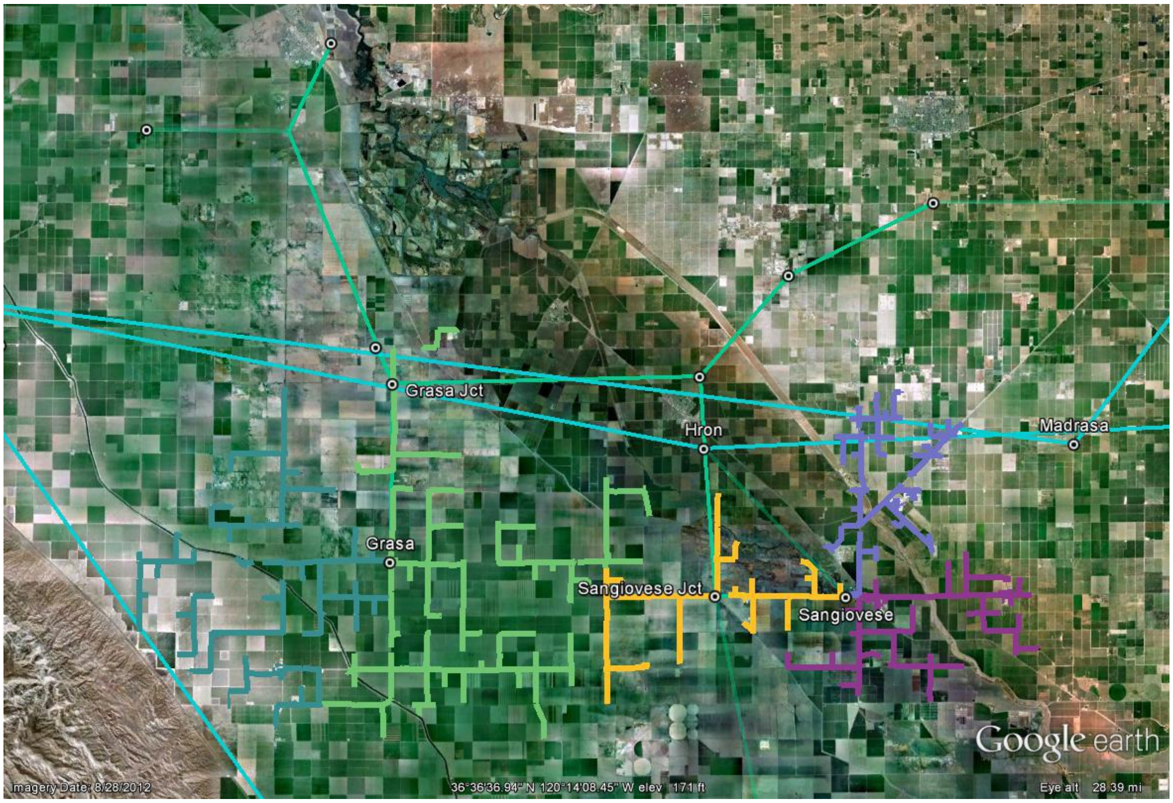
Hron 70 kV Operational Subnetwork

In the regional transmission network configuration represented in the data sets used for this study, Grasa Substation and Sangiovese Substation lie in a portion of the 70 kV network that is sourced from 230 kV at Hron Substation via a 134 MVA transformer. While Grasa and Sangiovese are served from Hron via separate 70 kV paths, these results indicate the wholesale PV interconnections proposed for those two substations and other interconnections within the 70 kV subnetwork served from Hron should be considered as a group.

Grasa Substation is electrically distinct from the other substations of the Gamay DPA—Cortese and Gamay—as Gamay is independently sourced from the 230 kV system, and Cortese lies in the Gamay 70 kV subnetwork. Sangiovese is electrically distinct from the other substations of the Madrasa DPA—Madrasa, Barbera, and Canaiolo—as Madrasa is independently sourced from the 230 kV system, and Barbera and Canaiolo are tied to Kotsifali at 70 kV. An open 70 kV tie from Sangiovese Junction to Semillon separates Sangiovese from the Gamay 70 kV subnetwork.

Hron 70 kV and the supporting 230 kV network are shown in **Figure 34**. The regional transmission lines are shown as dark turquoise (230 kV) and turquoise (70 kV), with the other colors representing the individual distribution feeders served from Grasa and Sangiovese Substations.

Figure 34: Hron 70 kV



Source: New Power Technologies.

In addition to the proposed interconnections at Sangiovese and Grasa identified in **Figure 34**, the California ISO queue identifies six projects representing 105,000 kW for interconnection at the Sangiovese Junction substation at 70 kV and six projects representing 243,700 kW for interconnection at Hron Substation at 70 kV.

Table 29 provides the project voltage impacts of the Sangiovese Junction and Hron Substation wholesale projects as directly estimated at each project site using the Energynet power flow simulation.

Table 29: Hron Project Voltage Impacts

					Minimum Daytime Load
ID	Interconnecting Bus	Bus Number	Rated Output (kW)	Type	Quasi-dynamic Voltage Impact (ΔV, % of Nominal)
I45	Sangiovese Jct Sub 70 kV bus	34456	20,000	PV	0.8
I46	Sangiovese Jct Sub 70 kV bus	34456	20,000	PV	0.8
I47	Sangiovese Jct Sub 70 kV bus	34456	20,000	PV	0.8
I48	Sangiovese Jct Sub 70 kV bus	34456	20,000	PV	0.8
I49	Sangiovese Jct Sub 70 kV bus	34456	20,000	PV	0.8
I50	Sangiovese Jct Sub 70 kV bus	34456	5,000	PV	0.2
I51	Hron Sub 70 kV bus	34474	11,750	PV	0.1
I52	Hron Sub 70 kV bus	34474	20,000	PV	0.2
I53	Hron Sub 70 kV bus	34474	20,000	PV	0.2
I54	Hron Sub 70 kV bus	34474	-	CC	0.0
I55	Hron Sub 70 kV bus	34474	23,000	PV	0.5
I56	Hron Sub 70 kV bus	34474	169,000	PV	-0.5

Source: New Power Technologies.

Within the Hron 70 kV subnetwork, where the distribution and substation interconnections under Sangiovese Substation induce reverse flow from Sangiovese to Hron Substation, the proposed interconnections at Sangiovese Junction Substation compete for the same 70 kV line capacity and have compounding voltage impacts. Furthermore, where distribution and substation connections under Grasa Substation induce reverse flow from Grasa to Hron Substation, the Grasa, Sangiovese, Sangiovese Junction, and Hron Substation 70 kV projects all compete for the same substation capacity at Hron Substation.

As described in **Table 26** of the Sangiovese Substation, a group composed of a portion of the interconnections proposed at or under Sangiovese substation, specifically Projects W42, W45, W43, and W46, would essentially fully use the available capability of the Hron-Sangiovese 70 kV path under daytime minimum load conditions with reverse flow exceeding the line rating of the Sangiovese-Sangiovese Junction portion. Again, under these conditions, the 105 MW of California ISO projects proposed for Sangiovese Junction at 70 kV listed in **Table 27** and in **Table 3** and **Table 4** would compete directly with these Sangiovese Substation projects for the Sangiovese Junction to Hron path. With this group of four projects connected, there is 23.5 MW of reverse flow from Hron 70 kV to Hron 230 kV, well under the 134 MVA normal rating of the substation transformer.

As described under Grasa Substation in **Figure 24**, a group composed of Projects W31 and W32 connected in Grasa feeders and Projects W29, W30, and W33 connected at Grasa substation at 12 kV would cause reverse flow exceeding the line rating on the 70 kV line between Grasa and Hron under minimum daytime load conditions. Any of the California ISO projects proposed for Grasa Substation at 70 kV would exacerbate that condition. With this group of five projects connected, there is 31.2 MW of reverse flow from Hron 70 kV to Hron 230 kV, well under the rating of the substation transformer.

Combining the group of four Sangiovese projects and five Grasa projects results in 73.1 MW of reverse flow from Hron 70 kV to Hron 230 kV, well under the rating of the substation transformer and with little voltage impact. Accordingly, there would be additional capability to accommodate the California ISO projects listed under each substation table and in **Table 3** and **Table 4** for interconnection at Hron 70 kV without overloading the Hron Substation transformer.

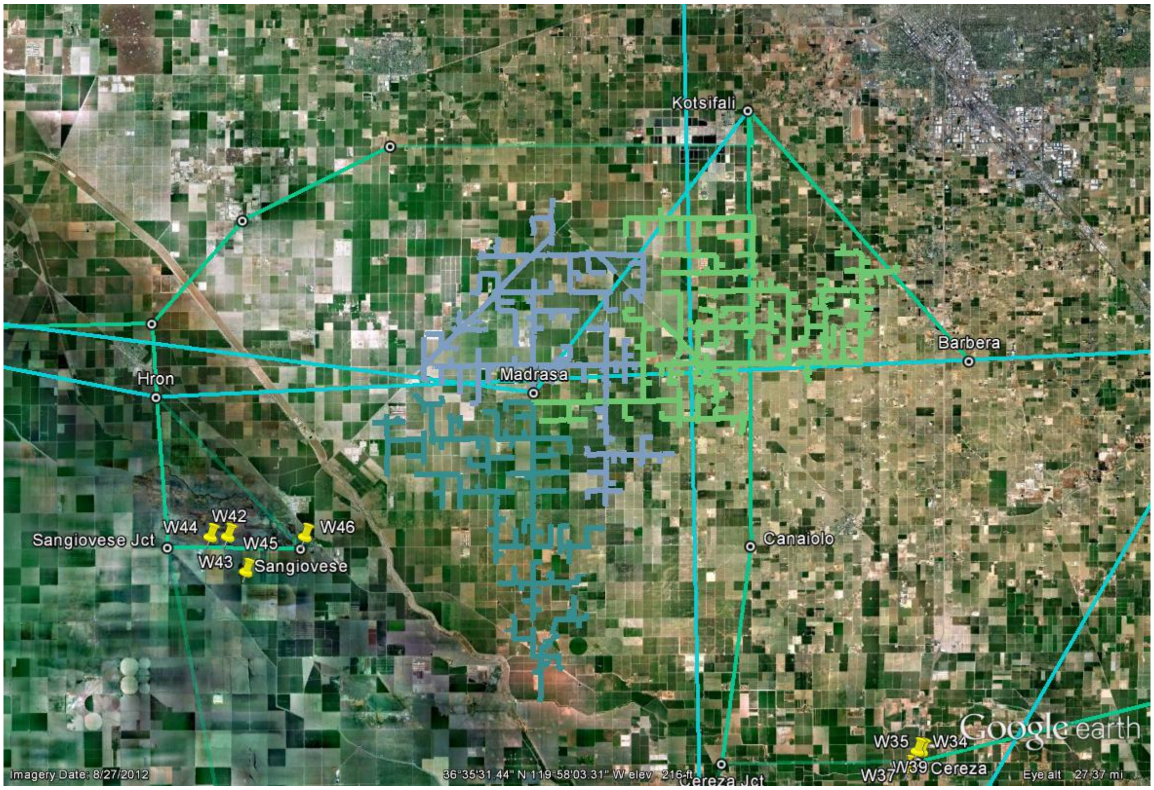
This also suggests that the limiting factor for the proposed interconnections under Hron 70 kV is the capability of the 70 kV system extending to Sangiovese and Grasa, as well as the step-down transformers at those substations. Considering the impacts of the same group of wholesale PV projects under peak load conditions, the overload between Sangiovese and Hron is eliminated, but a portion of the path from Grasa to Hron remains overloaded.

The Hron subnetwork and the Sangiovese and Grasa results provide a good example of a common occurrence in this study—that, in this power system with very high penetration of PV equipment, thermal limits are more limiting in practical terms than voltage impacts. This suggests that the ability to curtail wholesale PV under different load conditions might more directly improve the ability of the network to accommodate high penetrations of wholesale PV.

Madrasa 12 kV

Madrasa Substation serves three 12 kV distribution feeders, 1104, 1105 and 1106. Madrasa and the associated feeders are shown in **Figure 35**. The 230 kV lines are shown in turquoise, the 70 kV lines are shown in green, and the lines of the Madrasa feeders are shown in multiple colors.

Figure 35: Madrasa 12kV



Source: New Power Technologies.

Sangiovese, Madrasa, Barbera, and Canaiolo Substations and associated feeders are all nominally part of Madrasa DPA. However, Madrasa Substation and associated feeders are served directly from the Vineyard 230 kV transmission system and are electrically distinct from the 70 kV network and from Sangiovese, Barbera, and Canaiolo Substations. At the 230 kV level, Madrasa and Hron Substations are served in parallel from a common source, and Madrasa and Kotsifali are served in series.

The PG&E WDAT queue identifies no wholesale generation projects for interconnection at Madrasa Substation. New Power Technologies also did not identify any projects for connection at Madrasa in the California ISO queue. Madrasa Substation and the substation circuits are incorporated in the Energynet Vineyard model used for this study.

Kotsifali (Includes Canaiolo and Barbera Substations)

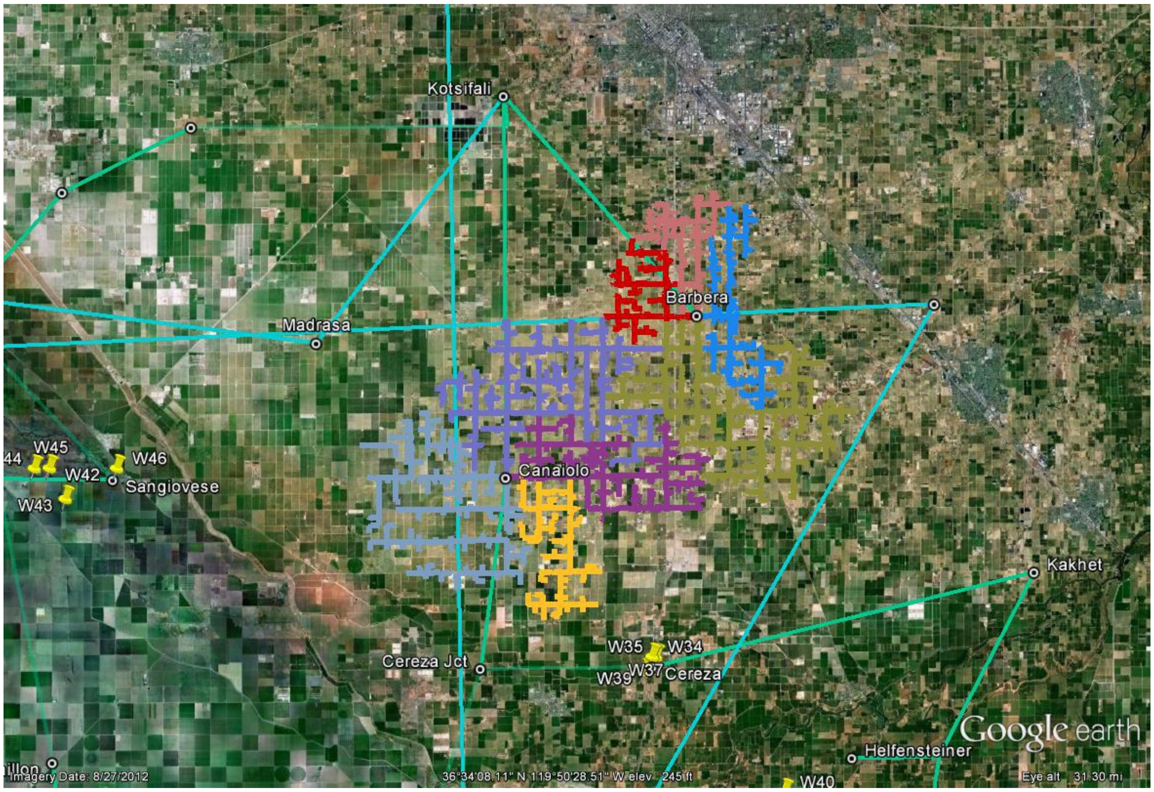
Kotsifali Substation is served from the Vineyard 230 kV system and connects at the 70 kV level.

Canaiolo Substation, Barbera Substation, and associated feeders are served from Kotsifali Substation at 70 kV. Open 70 kV ties separate Canaiolo and Barbera Substations from Kakhet and Hondarribi and the 70 kV subnetwork under Hron Substation. Accordingly, under this network configuration, Kotsifali, Canaiolo, and Barbera 70 kV substations may be considered as part of a common operational subnetwork. While Sangiovese, Madrasa, Barbera, and Canaiolo Substations and associated feeders are all nominally part of Madrasa DPA, Sangiovese and Madrasa Substations are electrically distinct from the subnetwork under Kotsifali Substation.

Canaiolo Substation serves four 12 kV distribution feeders—1101, 1102, 1104, and 1105—via 29 MVA and 18.8 MVA substation transformers. Barbera Substation serves four distribution feeders—110, 1102, 1103, and 1104—via a 17.6 MVA substation transformer.

The operational subnetwork under Kotsifali is shown in **Figure 36**. The regional transmission lines are shown as dark turquoise (230 kV) and turquoise (70 kV), with the other colors representing the individual distribution feeders served from Canaiolo and Barbera Substations.

Figure 36: Kotsifali 70kV



Source: New Power Technologies.

The PG&E WDAT queue identifies no wholesale generation projects for interconnection at either Canaiolo Substation or Barbera Substation. These substations and associated circuits are nonetheless incorporated in the Energynet Vineyard model used for this study.

From the California ISO queue, New Power Technologies identified one wholesale generation project, I38, nominally associated with Canaiolo Substation. This project is to be connected on the Canaiolo-Kakhet 70 kV line. This line includes open ties, and New Power Technologies modeled the project as connected at the Canaiolo 70 kV bus.

The California ISO project proposed for interconnection at Canaiolo 70 kV does not affect the Canaiolo Substation 70 kV to 12 kV transformer. Canaiolo Substation is served radially from Kotsifali at 70 kV via a line with a 31 MVA normal rating. Thus, Project I38 does not have the ability to overload the incoming 70 kV line under any load conditions.

Table 30 provides the project voltage impact of the Canaiolo California ISO project as directly estimated using the Energynet power flow simulation. Project I38 is relatively small for a transmission-connected project, and the voltage impact is modest.

Table 30: Canaiolo Substation-Connected Project Voltage Impact

					Minimum Daytime Load
ID	Interconnecting Bus	Bus Number	Rated Output (kW)	Type	Quasi-dynamic Voltage Impact (ΔV, % of Nominal)
gen_I38	Canaiolo Sub 70 kV bus	34512	7,000	PV	1.1

Source: New Power Technologies.

Hondarribi (Includes Lumassina)

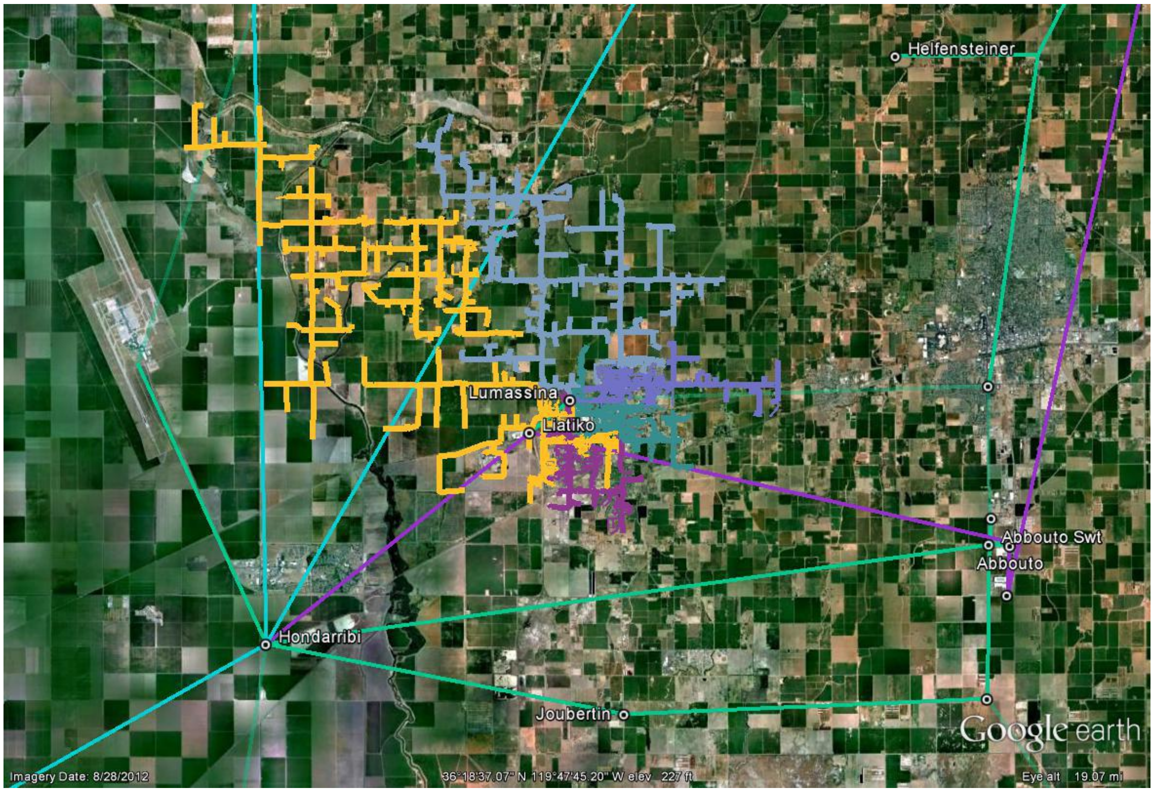
Hondarribi Substation is a significant element in the Vineyard power delivery system. Hondarribi is served at the 230 kV level and connects at the 115 kV and 70 kV levels.

At the 70 kV level, Hondarribi serves Lumassina Substation. Lumassina serves five 12 kV distribution feeders—1101, 1102, 1103, 1104, and 1105—which are nominally part of Lumassina DPA, along with the feeders served from Cereza and Helfensteiner Substations.

Due to open 70 kV ties between Hondarribi and Cereza Junction and between Abbouto Switch and Helfensteiner, Lumassina and the associated feeders are distinct from Cereza and Helfensteiner, even though those three substations and associated feeders are all nominally part of Lumassina DPA. Accordingly for this study, New Power Technologies consider Lumassina Substation as part of the operational subnetwork under Hondarribi 70 kV.

The operational subnetwork under Hondarribi, with Lumassina Substation and related feeders, is shown in **Figure 37**. The regional transmission lines are again shown as dark turquoise (230 kV) and turquoise (70 kV), with the other colors representing the distribution feeders served from Lumassina.

Figure 37: Hondarribi 70kV



Source: New Power Technologies.

The PG&E WDAT queue identifies no wholesale generation projects for interconnection at or under Lumassina Substation. From the California ISO queue, New Power Technologies identified 25 wholesale generation projects to be connected at or under Hondarribi Substation. Together, these represent 719,250 kW.

There is significant existing local power generation within the sub-network under Hondarribi. Under minimum daytime load conditions the 70 kV path from Hondarribi through Joubertin to Abbouto actually sends power to Hondarribi. As a consequence, each of the projects proposed for Abbouto Switch (Project I15) and Joubertin (Projects I27 through I31) effectively adds to the prevailing power flow.

Project I15 is relatively small, so while the path from Abbouto Switch to Joubertin substation is rated at only 39 MVA, Project I15 would not individually overload the path. The path from Joubertin to Hondarribi is rated at 72 MVA. So while adding to the prevailing power flow even the largest Joubertin interconnections at 20 MW would not individually overload the line.

Hondarribi at 70 kV imports about 50 MW from 230 kV under minimum daytime load conditions over a 200 MVA transformer, so it appears even the largest Hondarribi70 kV interconnection, I19 at 150,000 kW, would not individually result in an overload.

Hondarribi is also a net importer of about 45 MW from 230 kV to 115 kV over a 180 MVA transformer under minimum daytime load conditions, though with some existing generation under Hondarribi is shown as off under these operating conditions. So Project I37 at 20,000 kW would not individually result in an overload. Similarly, even the largest Hondarribi115 kV project at 100,000 kW would result in reverse flow of the 230/115 kV transformer but could not individually cause flow exceeding the transformer's 180 MVA rating. None of the other proposed Hondarribi115 kV interconnections would individually cause overloads or significant reverse flow.

Table 31 provides the individual project voltage impacts of the wholesale projects under Hondarribi as directly estimated at each project site using the Energynet power flow simulation. Individually these projects have modest voltage impacts.

Table 31: Hondarribi Project Voltage Impacts

					Minimum Daytime Load
ID	**Interconnecting Bus**	**Bus Number**	**Rated Output (kW)**	**Type**	**Quasi-dynamic Voltage Impact (ΔV, % of Nominal)**
I13	Hondarribi Sub 70 kV Bus	34540	12,000	PV	0.1
I14	Hondarribi Sub 70 kV Bus	34540	7,800	PV	0.1
I15	Abbouto Switch	34554	5,000	PV	0.1
I16	Hondarribi Sub 70 kV Bus	34540	20,000	PV	0.0
I17	Hondarribi Sub 70 kV Bus	34540	19,200	PV	0.2
I18	Hondarribi Sub 70 kV Bus	34540	-	CT	0.2
I19	Hondarribi Sub 70 kV Bus	34540	150,000	ST	0.0
I20	Hondarribi Sub 70 kV Bus	34540	15,000	PV	0.4
I21	Hondarribi Sub 70 kV Bus	34540	20,000	PV	0.1
I22	Hondarribi Sub 70 kV Bus	34540	17,750	PV	0.2
I23	Hondarribi Sub 70 kV Bus	34540	20,000	PV	0.1
I24	Hondarribi Sub 70 kV Bus	34540	20,000	PV	0.2
I25	Hondarribi Sub 70 kV Bus	34540	20,000	PV	0.2
I26	Hondarribi Sub 70 kV Bus	34540	10,000	PV	0.2
I27	Joubertin Sub 70 kV bus	34542	20,000	PV	0.1
I28	Joubertin Sub 70 kV bus	34542	13,500	PV	0.1
I29	Joubertin Sub 70 kV bus	34542	20,000	PV	0.1
I30	Joubertin Sub 70 kV bus	34542	20,000	PV	0.1
I31	Joubertin Sub 70 kV bus	34542	20,000	PV	0.1
I32	Hondarribi Sub 115 kV Bus	34430	49,000	Other	0.2
I33	Hondarribi Sub 115 kV Bus	34430	100,000	PV	0.3
I34	Hondarribi Sub 115 kV Bus	34430	20,000	PV	0.1
I35	Hondarribi Sub 115 kV Bus	34430	20,000	PV	0.1
I36	Hondarribi Sub 115 kV Bus	34430	80,000	PV	0.2
I37	Liatiko Sub 115 kV Bus	34521	20,000	PV	0.3

Source: New Power Technologies.

DG Interconnection Groups

As noted, under minimum daytime load conditions the 70 kV generation projects on the Hondorribi-Joubertin-Abbouto path all have directly compounding impacts, adding to the existing flow to Hondarribi substation at 70 kV under minimum daytime load conditions. Further, the Abbouto project and the Joubertin projects as a group represent 78,500 MW which could overload the 72 MVA 70 kV line to Hondarribi with no offsetting load.

Project I37 and the five Hondarribi Substation 115 kV projects as a group represent 289 MW. Thus as a group they could overload the 180 MVA 230 kV to 115 kV transformer at Hondorribi.

Cereza

Cereza substation serves five 12 kV distribution feeders, 1102, 1103, 1104, and 1105, via 29.7 MVA and 10.5 MVA 70 kV to 12 kV transformers.

The PG&E WDAT queue identifies six wholesale generation projects for interconnection at or under Cereza Substation—five at feeder locations within Cereza 1104, identified as Project W41 and Projects W36 through W39, and one at a feeder location in Cereza 1102, Project W35.

From the California ISO queue New Power Technologies identified one wholesale generation project, I12, to be connected at the at the Cereza substation 70 kV bus.

Distribution Feeder Interconnections

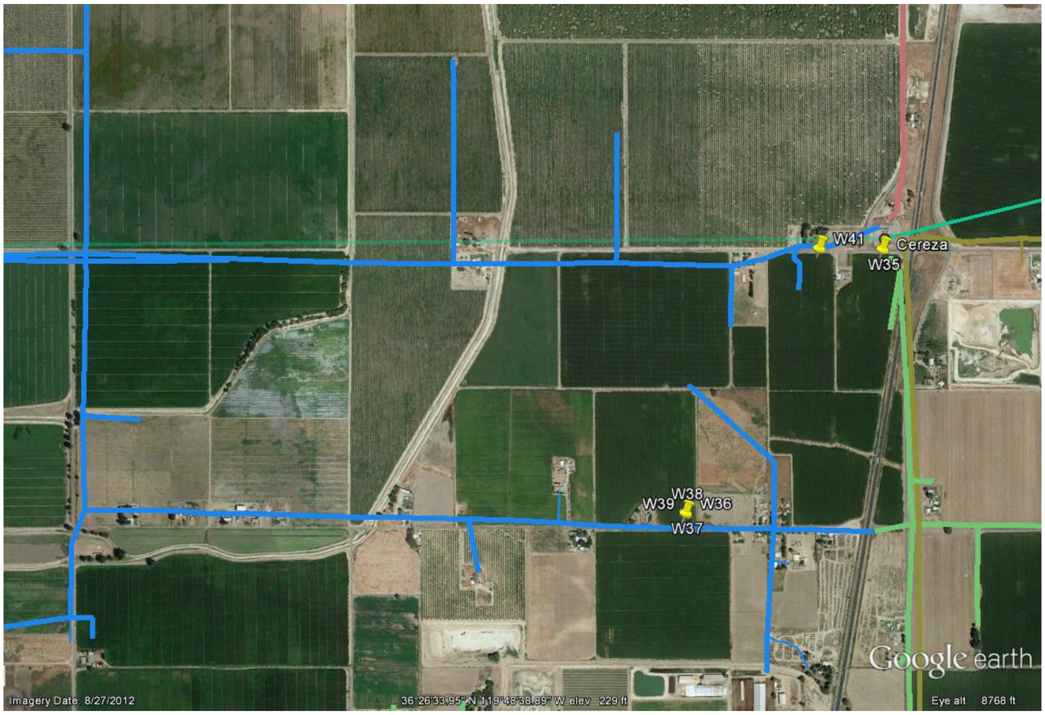
Table 32 lists the Cereza feeder-connected WDAT projects and provides details concerning the distribution network at the point of interconnection for each project. The projects locations are shown in **Figure 38** along with portions of Cereza Feeder 1104 and Feeder 1102. In each case the interconnecting bus was determined by New Power Technologies as the existing network bus closest to the project, established through geocoding the project's location. In Feeder 1104, Projects W36 through W39 are co-located.

Table 32: Cereza Feeder-Connected Project Site Characteristics

ID	Interconnecting Bus	Bus Number	Rated Output (kW)	Ckt Reverse Flow Limit (MVA)	Minimum Upstream Rating (MVA)	System X/R	Utility Source SC (MVA)	Voltage Impact Ratio
W35	Bus_F252301102_struc_1401	716007	1,500	1.6	14.6	4.2	2130.5	1420.4
W36	Bus_F252301104_struc_1279	718721	1,500	3.2	4.2	1.3	35.7	23.8
W37	Bus_F252301104_struc_1279	718721	1,500	3.2	4.2	1.3	35.7	23.8
W38	Bus_F252301104_struc_1279	718721	1,500	3.2	4.2	1.3	35.7	23.8
W39	Bus_F252301104_struc_1279	718721	1,500	3.2	4.2	1.3	35.7	23.8
W41	Bus_F252301104_fus_93	718233	1,500	3.2	2.6	2.3	786.6	524.4

Source: New Power Technologies.

Figure 38: Cereza Feeder Interconnections



Source: New Power Technologies.

Cereza 1102 and 1104 both have multiple voltage boosters and line voltage regulators. Thus, the existing system offers some circuit-level voltage regulation capability for generation interconnections on those feeders.

The circuit reverse flow limit for Feeder 1102 indicates that W35 does not have the capability to induce export out of Cereza 1102. The reverse flow limit for Feeder 1104 likewise indicates that none of the five Feeder 1104 projects individually has the capability to induce export out of Cereza 1104.

The Feeder 1102 project and the Feeder 1104 projects are all also well under the minimum upstream line ratings for their respective points of interconnection, meaning none of these projects alone could cause an overload under any load conditions.

The Feeder 1102 project and the Feeder 1104 projects are all also located at strong network locations, as indicated by their voltage impact ratios. The weakest location is that of Projects W36 through W39, yet the voltage impact ratio at that location for any one of those projects is well over 5.0.

The feeder site for Project W41 and the site for Projects W36 through W39 in Feeder 1104 and the site for Project W35 in Feeder 1102 have no reclosers or voltage regulators between each site and the substation, so interconnecting projects at either location would not require evaluation for rapid reclosing into an energized island or reverse flow through a voltage regulation device. This preliminary evaluation suggests that feeder interconnection site for the Feeder 1102 project and the Feeder 1104 projects (considered individually) may be low-impact.

Substation Interconnections

Project I12 connected at the Cereza substation 70 kV bus would not directly impact the loading of the Cereza substation transformer and is well under the rating of the incoming 70 kV transmission line serving Cereza.

Table 33 provides the individual project voltage impacts of the Cereza Substation wholesale projects as directly estimated at each project site using the Energynet power flow simulation.

Table 33: Cereza Project Voltage Impacts

					Minimum Daytime Load
ID	**Interconnecting Bus**	**Bus Number**	**Rated Output (kW)**	**Type**	**Quasi-dynamic Voltage Impact (ΔV, % of Nominal)**
W35	Bus_F252301102_struc_1401	716007	1,500	PV	0.2
W36	Bus_F252301104_struc_1279	718721	1,500	PV	2.0
W37	Bus_F252301104_struc_1279	718721	1,500	PV	2.0
W38	Bus_F252301104_struc_1279	718721	1,500	PV	2.0
W39	Bus_F252301104_struc_1279	718721	1,500	PV	2.0
W41	Bus_F252301104_fus_93	718233	1,500	PV	0.2
I12	Cereza Sub 70 kV bus	34508	14,000	PV	1.8

Source: New Power Technologies.

For the feeder interconnections of Projects W35 through W41 these results confirm the outcomes suggested by the voltage impact ratios depicted in **Table 30**—changes in output from these projects have relatively little voltage impact due to the relative strength of the system at each interconnection location. A 100 percent output change of any of these projects would cause a quasi-dynamic voltage change equal to well under 3 percent of nominal voltage under minimum daytime load conditions. The California ISO queue project at Cereza substation also has modest voltage impacts.

The 1.5 MW wholesale PV projects under Cereza provide a good example of interconnections that are the same size in terms of output, physically near each other, and in the case of W41 and Projects W36 through W39, connected to the same circuit, but that have very different impacts due to their point of interconnection within the feeder. Projects W36 through W39 are physically close to W35 and W41, which are, in turn, close to the substation. However, connecting at the nearest Feeder 1104 bus would place the interconnection point for Projects W36 through W39 at some distance from the substation in circuit terms, and especially distant from W35 on Feeder 1102. Accordingly, the system X/R ratio and voltage impact ratio for these projects evaluated at their point of interconnection are very different and their voltage impacts are different by an order of magnitude.

DG Interconnection Groups

Projects W36 through W39 individually appear to be feasible feeder interconnections, though they share a common interconnection point. Together, they represent 6,000 kW. Given the Feeder 1104 reverse flow limit of 3.2 MVA, these projects as a group could cause and feeder export under some load conditions. These projects as a group also exceed the minimum upstream line rating for their point of interconnection, introducing the possibility of overloading upstream equipment under some load conditions.

The voltage impact ratio for these projects as group is 6.0; this is still indicative of a relatively strong interconnection location.

In the Energynet simulation under minimum daytime load conditions, under a 100 percent simultaneous output change event these projects have a quasi-dynamic voltage impact of 7.1 percent of nominal voltage, which is probably not acceptable without mitigation. As noted, Feeder 1104 has circuit level voltage controls, though there are no voltage regulating devices between the interconnection point for Projects W36 through W39 and the substation. The steady-state voltage impact (after the actuation of taps and automated capacitors) of a 100 percent simultaneous output change event for these projects has a voltage impact at the project site of 5.6 percent of nominal voltage. The combined output of these projects also causes overloads of some upstream line segments in Feeder 1104 and results in export out of Feeder 1104 and reverse flow across the 29.7 MVA Cereza substation transformer serving Feeder 1104.

Adding Project W41 to the group adds to the Feeder 1104 export and reverse flow over the 29.7 MVA transformer bank, but does not add any new overloads or cause high voltage at the project location.

Project W35 and Feeder 1102 are served from the other Cereza substation transformer bank and Project W35 does not cause any reverse flow, high voltage or overloads. With all of the Cereza feeder-connected projects on Cereza substation remains a net importer under minimum daytime load conditions.

Cereza substation is served essentially radially at 70 kV from Kakhet substation due to the open tie from Cereza to Cereza Junction. The incoming 70 kV line is rated at about 42 MVA, which is more than the combined output of the Cereza WDAT projects and the Cereza California ISO project, so these projects as a group cannot overload the incoming 70 kV system. With all of these projects operating (23 MW total) under minimum daytime load conditions there is reverse flow to Kakhet substation and reverse flow across the Kakhet 115 kV to 70 kV transformer, but no overloads or high voltage. In this configuration the reverse flow across voltage regulation points occurs at the one Cereza substation transformer and the Kakhet substation transformer.

Helfensteiner

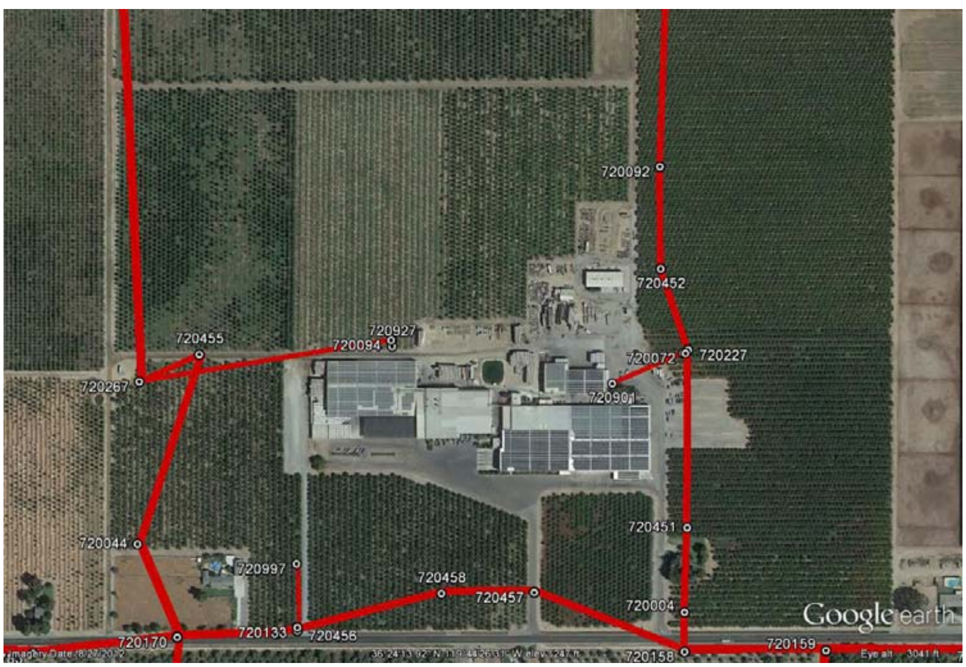
Helfensteiner substation serves two 12 kV distribution feeders, 1102 and 1102, via a 15 MVA 70 kV to 12 kV transformer.

The PG&E WDAT queue identifies one wholesale generation project associated with Helfensteiner substation, with interconnection at a feeder location within Helfensteiner 1101, identified as W40.

From the California ISO queue New Power Technologies identified one wholesale generation project, I11, to be connected at the at the Helfensteiner substation 70 kV bus.

Helfensteiner 1101 has about 1,025 kW of existing generation, including the 793 kW project shown in Figure 39 with portions of Helfensteiner Feeder 1101. New Power Technologies estimates the Feeder 1101 minimum daytime load at 2,050 kW, thus a substantial share of the circuit's load is already served from generation within the feeder.

Figure 39: Existing Helfensteiner Feeder-Connected PV



Source: New Power Technologies.

Distribution Feeder Interconnections

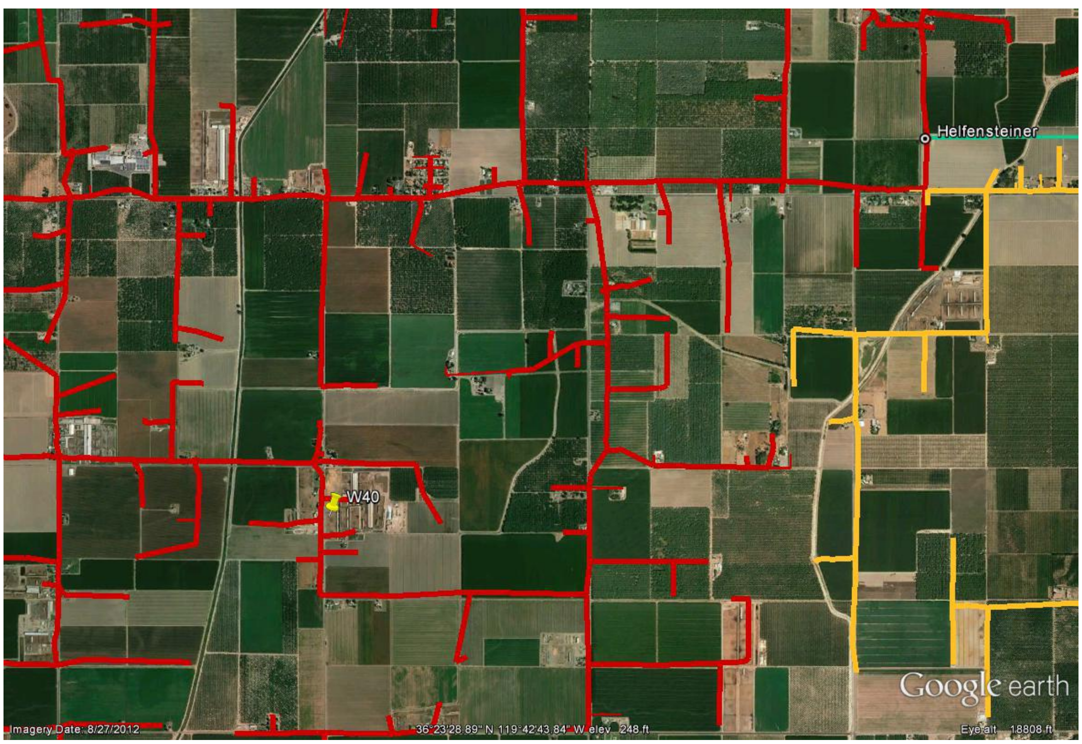
Table 34 lists the Helfensteiner feeder-connected WDAT project and provides details concerning the distribution network at the point of interconnection. The project's location is shown in **Figure 40** along with the Helfensteiner distribution feeders in various colors and the 70 kV transmission line serving Helfensteiner in turquoise. The interconnecting bus was determined by New Power Technologies as the existing network bus closest to the project, established through geocoding the project's location. Project W40 is a reciprocating engine project located fairly distant from Helfensteiner substation.

Table 34: Helfensteiner Feeder-Connected Project Site Characteristics

ID	Interconnecting Bus	Bus Number	Rated Output (kW)	Ckt Reverse Flow Limit (MVA)	Minimum Upstream Rating (MVA)	System X/R	Utility Source SC (MVA)	Voltage Impact Ratio
W40	Bus_F253711101_struc_838	721081	925	1.0	2.3	0.9	24.6	26.6

Source: New Power Technologies.

Figure 40: Helfensteiner Feeder Interconnection



Source: New Power Technologies.

Helfensteiner 1101 has multiple voltage boosters and line voltage regulators, thus the existing system offers some circuit-level voltage regulation capability for generation interconnections on this feeder. One of the voltage regulators lies between the W40 project site and the substation.

The circuit reverse flow limit for Feeder 1101 is small due to the large existing generator in the feeder. However, W40 is still small enough that it does not have the capability to induce export from Feeder 1101.

Project W40 is also well under the minimum upstream line rating for its point of interconnection, meaning the project alone could not cause an overload under any load conditions. Project W40 is located at a reasonably strong network location as indicated by the voltage impact ratio for the project.

The feeder site for Project W40 Feeder 1101 has a recloser between the site and the substation, so interconnecting the project at that location would require evaluation for rapid reclosing into an energized island. This preliminary evaluation suggests that the feeder interconnection sites for Project W40 may be low-impact, with some potential for voltage impacts.

Substation Interconnections

The incoming 70 kV line serving Helfensteiner substation is rated at 42 MVA, though there is a more-limiting 39.4 MVA 70 kV line between Helfensteiner and Kakhet substation. So neither Project W40 nor Project I11 has the capability individually to overload the incoming 70 kV system serving Helfensteiner.

Table 35 provides the individual project voltage impacts of the Helfensteiner substation wholesale projects as directly estimated at each project site using the Energynet power flow simulation.

Table 35: Helfensteiner Project Voltage Impacts

					Minimum Daytime Load
ID	**Interconnecting Bus**	**Bus Number**	**Rated Output (kW)**	**Type**	**Quasi-dynamic Voltage Impact (ΔV, % of Nominal)**
W40	Bus_F253711101_struc_838	721081	925	Recip	2.0
I11	Helfensteiner Sub 70 kV bus	34458	13,400	PV	1.8

Source: New Power Technologies.

For the feeder interconnections of Project W40 these results confirm the outcomes suggested by the voltage impact ratio depicted in **Table 32**—changes in output from this project has relatively little voltage impact due to the relative strength of the system at each interconnection location. A 100 percent output change of W40 would cause a quasi-dynamic voltage change equal to under 3 percent of nominal voltage under minimum daytime load conditions. The California ISO queue project at Helfensteiner substation also has modest voltage impacts.

DG Interconnection Groups

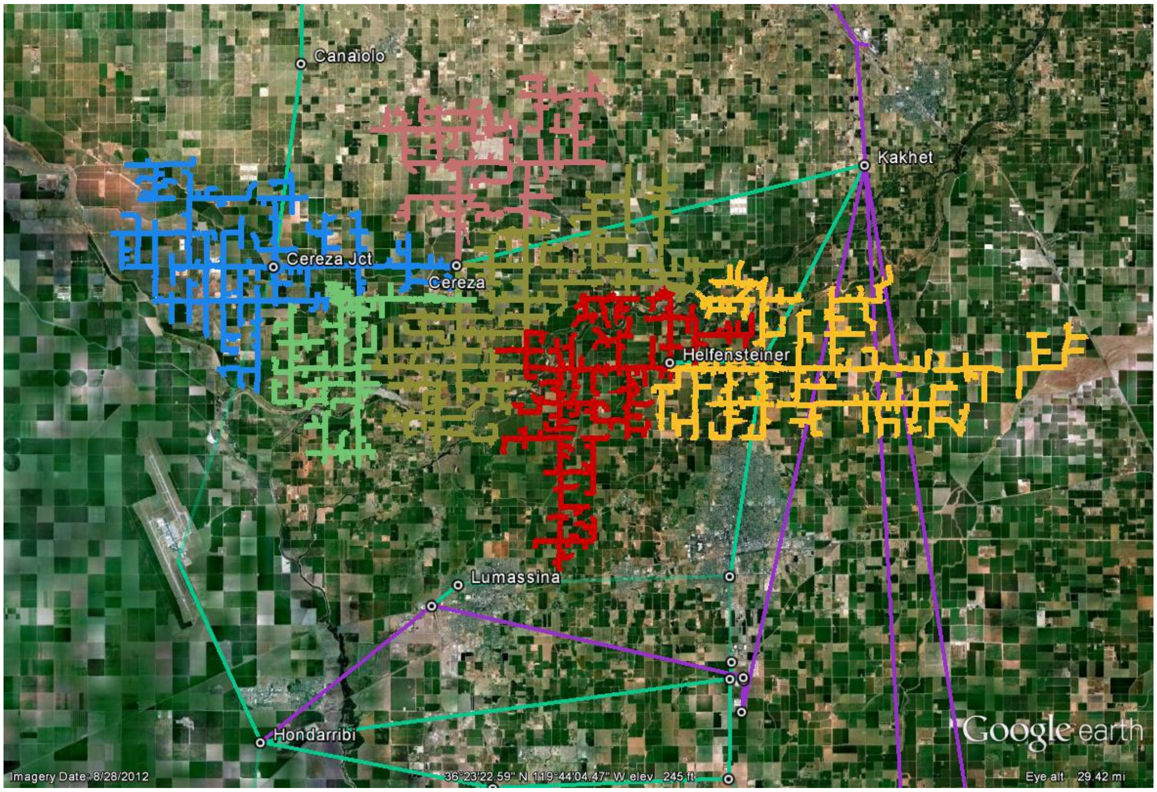
Projects W40 and I11 individually appear to be feasible interconnections. These two projects as a group would not result in unacceptably high voltage or overloaded equipment. In the Energynet simulation with both projects operating under minimum daytime load conditions, Helfensteiner substation becomes a net exporter. The 70 kV system serving Helfensteiner is characterized at a relatively high voltage in the light load base case (around 4 percent over nominal voltage), so with the addition of these two projects the voltage at the Helfensteiner substation at 70 kV rises to over 5 percent over nominal.

Kakhet 70 kV

Helfensteiner substation and Cereza substation and their circuits are served from Kakhet substation at 70 kV. Open ties effectively separate this portion of the 70 kV network from Kotsifali and Hondarribi. Kakhet is served from the Vineyard 115 kV system.

Cereza and Helfensteiner are served via separate 70 kV paths. However, where wholesale PV at or under those substations results in reverse flow back to Kakhet, those projects could affect potential interconnections at or under Kakhet 70 kV. Accordingly, New Power Technologies considers the Helfensteiner and Cereza interconnections as belonging to a group for evaluation under Kakhet 70 kV. The operational sub-network under Kakhet is shown in **Figure 41**. The regional transmission lines are shown as dark turquoise (230 kV), dark orchid or purple (115 kV) and turquoise (70 kV), with the other colors representing the individual distribution feeders served from Helfensteiner and Cereza substations.

Figure 41: Kakhet 70kV



Source: New Power Technologies.

As described, the WDAT and California ISO queues include nine projects totaling 37,325 kW for interconnection at Helfensteiner or Cereza substations under Kakhet 70 kV. The discussion for the projects of each substation shows that incorporating the output of all of these projects as substation groups under minimum daytime load conditions results in a local overload within Cereza 1104 and slightly elevated voltage at Helfensteiner substation at 70 kV. The 70 kV radial lines from Kakhet to both substations also see reverse flow back to Kakhet substation.

Further combined as a single group under Kakhet 70 kV, the reverse flow from the projects of each substation compounds at Kakhet as reverse flow through the 115 kV to 70 kV Kakhet substation transformer. However, the 24 MW reverse flow does not approach the 90 MVA normal rating of the transformer.

CHAPTER 4: Discussion and Conclusions

This project is intended to demonstrate and evaluate the potential of an approach that departs from conventional practice in its use of a model integrating distribution and transmission to evaluate the regional grid impacts of wholesale PV projects where their output is high relative to local load, or there is high penetration. The study is not intended to conclusively determine the suitability of interconnection of any of the proposed wholesale generation projects, prescribe necessary mitigation, or supplant the established interconnection process and study efforts underway by PG&E and the California ISO.

A Coupled Transmission and Distribution Analysis Provides New Visibility

These results show that a system-level, integrated transmission and distribution analysis approach that incorporates all of the feeders in a regional system and fully couples transmission and distribution provides a new level of visibility into the impacts of these wholesale projects, particularly in groups and where distribution-connected projects have impacts extending beyond a single feeder through the substation and into the transmission system.

The foregoing discussion enumerates direct impacts of individual projects and groups of projects in detail, covering loading, steady state and quasi-dynamic voltage, and impacts on individual devices and lines, in distribution, within the substations, and in transmission. The results directly show impacts extending from distribution to transmission and from transmission to distribution that would not visible in distribution-only or transmission-only study. The results also reveal interconnection group relationships and behavior that are wholly independent of the DPA distribution-connected projects' host feeders may belong to or substations they are served from, but that stem from network features several voltage levels higher in the transmission system.

This additional visibility may also reveal considerations that were previously not readily apparent and may be unexpected. One example is Projects W30 and I9 associated with Grasa substation. The interconnection of Project W30, nominally a distribution project, results in no overloads or voltage violations. Likewise, the interconnection of Project I9, nominally a transmission project, results in no overloads or voltage violations. However, the integrated model reveals that Project W30 induces reverse flow on the transmission line serving Grasa substation such that, if the normal rating of that line is a constraint, there is not sufficient capacity to accommodate Project I9. Other examples include the Kadarka projects which overload transmission but not distribution, the pervasiveness of distribution transformer overloads, and the relative absence of significant or far-reaching transmission voltage impacts.

Having transmission and many distribution feeders together and directly at hand in a single model also facilitates the evaluation of interconnection alternatives. As one example, in these results Project W6 at Aleatico substation is evaluated as a substation-connected project, as feeder-connected project, and as a split project with connections in two feeders, all within one model.

Further, by showing the distribution, substation, and transmission impacts directly alongside one another, this approach may suggest new ways to addressing those impacts. The pervasive substation transformer overloads suggest consideration of connecting WDAT projects at substations at the transmission-level voltage. The transmission impacts of the distribution-connected Trepat projects (W9 and W10) suggest reconfiguration of the 70 kV transmission as an impact mitigation strategy.

As the Energynet simulation demonstrated in this project is extended to additional regional distribution planning areas, it provides a platform for easy evaluation of the impacts of many regional wholesale PV project interconnections, alternative interconnection schemes for those projects, different project grouping or ordering, and different configurations of the regional power delivery system to address various impacts. This should help identify low-cost interconnection solutions and speed interconnection evaluations, facilitating the deployment of wholesale PV projects.

According to PG&E, interconnection requests are presently routinely evaluated using their decoupled distribution feeder load flow program; it is fair to ask when such an approach might be useful.[24] The interconnection backlog[25] reported by utilities suggests that present analysis methods do not offer an advantage in terms of time or effort. The methods of this study do not address every interconnection issue, and conventional methods and tools would likely be used alongside. The approach of this study might yield little additional insight in the evaluation of projects meeting all of the following four conditions:

- The generation project and any others on the feeder are shown to have no chance of exporting power beyond the feeder under any load conditions, and thus have no chance of influencing assets not represented in the single-feeder model.

24 New Power Technologies did not review or evaluate the methods or tools used by PG&E for interconnection studies as part of this work authorization.

25 Southern California Edison, *Amendments to Wholesale Distribution Access Tariff to Revise the Generator Interconnection Procedures*, page 7 of 43, March1, 2011.

- It is shown that there are no generation projects or other assets elsewhere in the system that would be affected by a change in the net load of the feeder in question under any load conditions (for example, a generator on a neighboring feeder or upstream whose output now causes a flow reversal).
- The generation project and any others on the feeder are shown to have no voltage impacts that would trigger a response from a voltage control that influences other portions of the network (for example, a TCUL for a transformer that serves other feeders).
- It is known that there will be no need to evaluate alternative interconnection schemes for the project that would involve assets outside the single-feeder model (for example, interconnection directly to the substation via an express feeder or connection to a neighboring feeder).

The results of this study indicate that these conditions are often not met when considering wholesale PV interconnections. Moreover, when multiple projects are at issue, it might require a system-level integrated transmission and distribution model simply to confirm that these conditions are met.

High Penetrations of Distribution-Connected Generation Projects Affect Regional Transmission

Every project group discussed in Chapter 2 that includes distribution-connected generation was shown to have influence at the feeder level, the substation level, and at the transmission level. In the case of the Aleatico projects, the impact extended through the 70 kV transmission system to the higher-level 230 kV system, with impacts extending over 60 miles away. The Bonarda substation interconnections provide another example of the influence of distribution projects on transmission. In this case the distribution-connected (WDAT) projects consume the capability of the incoming 70 kV line serving Bonarda in terms of voltage and line loading. If those distribution projects were interconnected, they would effectively preclude the connection of a group of transmission-connected (California ISO) projects in that queue.

These results do not address every possible transmission-level impact. The scope of this study did not include contingency conditions, system protection, or impacts on deliverability. New Power Technologies also did not attempt to identify and evaluate all relevant groupings of projects within the region. To illustrate, the study area for this analysis, based initially on several DPAs, did not include Caladoc substations and their feeders as noted, which clearly include projects whose impacts should be considered in the Gamay 70 kV sub-network group.

These results are sufficient to show that at least in this part of the California power delivery network a decoupled evaluation of proposed distribution interconnections that considers only distribution impacts or, for that matter, evaluation of only transmission impacts of transmission interconnections alone reveals just a part of the picture.

All Interconnections are Different

These results include individual evaluations of a common class of distributed generation (wholesale PV), but beyond that a wide variety of projects in terms of their size, type of interconnection (feeder, substation high-voltage bus, substation low-voltage bus), system characteristics, and system features at the point of interconnection. The key finding here is it is difficult to draw generally-applicable conclusions about the impacts of particular types of interconnections that are actionable. On the contrary, the most important findings may be the outliers.

Projects W25 and W27 under Gamay 12 kV represent good examples of relatively large wholesale PV projects (10 and 5 MW respectively) physically located away from the substation, but where direct connection to the 12 kV distribution feeder adjacent to the project site would neither risk overloading the feeder nor have unmanageable network voltage impacts, even under light load conditions. At the same time, Project W23 in Dolcetto is a good example of a much smaller project (1.5 MW) with a big impact on a 12 kV feeder due to the system weakness at the interconnection location.

Such results show that it is difficult to generalize or guess at interconnection impacts or issues for a given project or even the capability of a given feeder to accommodate wholesale PV. Terms like “high” penetration, “moderately sensitive” delivery network environment, “typical” or “rural” feeders, or even “small” or “large” generation project provide little rigorous guidance for the issues associated with an individual interconnection. These results show clearly that individual interconnections have different impacts depending on both the characteristics of the project and the characteristics of the power delivery network at the point of interconnection, and the characteristics of other interconnections where there may be group interaction. Best practice suggests that such projects warrant individual attention.

These results also show that a regional power system simulation with integrated transmission and distribution, and many distribution feeders represented in full detail readily shows many of the direct impacts of PV projects proposed within the region, individually and in various groups. This suggests that evaluating large numbers of potential projects under different interconnection schemes, in different groupings, or under different regional network configurations could become straightforward task that could be completed quickly and on an ongoing basis to inform and guide developer decisions.

Distribution-Connected Projects are Different From Transmission-Connected Projects

These results clearly show that to equivalize a group of proposed distribution-connected PV projects and simulate them as a single transmission-level interconnection can misrepresent their impacts.

The Tibouren substation projects as a group have a relatively benign impact on transmission with reverse flow to Acolon substation. However, modeling these projects at their individual points of interconnection in the substation or out on the distribution feeder reveals their potential for overloads of the substation transformer and line segments within the feeder.

Modeling the two Kadarka distribution feeder-connected projects, W7 and W8, at their appropriate points within the circuit shows how their voltage impact at the point of interconnection essentially disappears as seen at the substation or in the transmission system.

As another example, the feeder-connected and substation-connected alternatives for Projects W25 and W27 under Gamay 12 kV show the differences that may arise in representing a feeder-connected project at the substation vs. at its circuit location. At the substation, both projects have essentially no voltage impact. However, at their in-feeder locations, both projects do have observable (though potentially acceptable) voltage impacts on the feeder as evaluated at their point of interconnection. Moreover, due to the differences in the strength of the network at each feeder location relative to the size of each project, the voltage impacts of the two projects at their feeder locations are significantly different.

Projects W25 and W27 and the Grasa results also provide examples where wholesale projects identified for connection at substations might be feasibly connected at points on existing nearby distribution circuits, possibly with less difficulty and lower cost.

Distribution-Connected Projects are Different From Each Other

The distribution-connected projects associated with Bonarda and Kadarka substation provide excellent examples of the differences in impacts of similar projects in different locations. Project W6 evaluated in two locations in Kadarka 1104 represents in effect identical projects in the same feeder but at different locations that have very different voltage impacts due to differences in the relative network weakness at each location. W7 and W8 within Kadarka are in strong locations and have modest impacts. W14 and W22 in Bonarda are similar in size to each other but also have very different impacts compared to each other. They are also both in weaker locations (and are larger) and have much greater impacts than projects W7 and W8. Again, Project W23 in Dolcetto is a good example of a small project with a big impact due to the system weakness at the interconnection location.

The 1.5 MW wholesale PV projects under Cereza provide another good example of interconnections that are the same size in terms of output, physically near each other, and in the case of W41 and Projects W36 through W39, connected to the same circuit, but that have very different impacts due to their point of interconnection within the feeder. Projects W36 through W39 are physically close to W35 and W41, which are, in turn, close to the substation. However, connecting at the nearest Feeder 1104 bus would place the interconnection point for Projects W36 through W39 at some electrical distance from the substation, and especially electrically distant from W35 on Feeder 1102. Accordingly, the system X/R ratio and voltage impact ratio for these projects are very different and their voltage impacts are different by an order of magnitude.

These results show that the network impact of a given feeder-connected project can differ depending on differing network attributes within the feeder. Such differences might be distorted where simplifying assumptions are made on the internal characteristics of the feeder as with the use of representative feeders or reduced feeder models in the analysis. Such differences would be lost entirely where the project is represented as connected at the substation.

To fairly assess the impacts of feeder-connected interconnections they must be evaluated individually, taking into account the attributes of their actual point of interconnection within the circuit as appropriate.

Transmission-Connected Projects are Different From Each Other

The wholesale projects associated with Gamay and Grasa identified in the WDAT queue and particularly those in the California ISO queue have dramatically different aggregate impacts on the transmission system. The Gamay projects represent far more capacity, but have little impact on transmission assets in terms of power flow, loading, and voltage. The Grasa projects represent little capacity but result in significant overloads of the regional transmission system, even under normal operating conditions where local load is being served.

In this instance, the impact difference for projects in these different locations is likely due to the fairly unusual feature of the Gamay substation where the distribution feeders and substation are served from the 230 kV level. The 70 kV network that more typically serves the distribution substations in the Vineyard power delivery system has much lower line ratings.

Groups of Projects With Interactions or Compounding Impacts are Hard to Identify by Observation

New Power Technologies evaluated projects in various groups—projects at a common point of interconnection, on a common feeder and at or under a common substation.

With the addition of the California ISO queue projects during the course of the study, New Power Technologies also found that groups of projects could have compounding impacts on the power delivery network or affect the same infrastructure even though they may be in feeders in different DPAs, under different substations, or from different interconnection queues altogether.

These relationships only became evident as individual projects were evaluated within the context of the full distribution and transmission network. The key finding is that these groups emerged as a result of the analysis, not as a precursor to the analysis.

Detailed, accurate distribution feeder maps would have been required to determine the common substation grouping of the WDAT projects even if this analysis had not extended to distribution detail—for example, Project W23 began the study nominally associated with a different substation. With detailed, accurate distribution feeder topology incorporated in the integrated, regional model, grouping by substation is an easy, reasonable first pass.

The Kadarka and Aleatico substation projects represent a clear example of projects under different distribution substations that are electrically interdependent due to the alignment of the upstream transmission. The analysis shows that both sets of projects can affect the 70 kV transmission system between Gamay and Aleatico and because of the presently modeled alignment of the 70 kV system with the tie to Trepat open, their impacts are largely additive.

Similarly, the analysis also shows that the WDAT projects associated with Bonarda and Tibouren substations both have effects visible at Acolon substation, even though they affect different parts of the downstream 70 kV system. However, the analysis also shows projects in the California ISO queue as well as the WDAT queue associated with other substations that have interrelated effects.

It is also notable, for example, that Charbono and Bonarda substations are administratively related within the Bonarda DPA. Their circuits are also physically close to each other. However, the detailed Energynet system characterization shows that under the present 70 kV alignment, as long as the distribution feeders in Bonarda DPA are operated radially with open inter-circuit ties, there would be essentially no electrical connection between wholesale projects connected on circuits served from those two substations. As another example, the WDAT and California ISO queue projects at the Grasa substation are separated by virtue of different queue processes. However, these results show they have directly additive impacts on the same power delivery assets.

Projects W5 and W6 associated with Aleatico substation, W31 and W32 associated with Grasa substation, W22 associated with Bonarda substation, and W44 and W46 associated with Sangiovese substation are identified in the WDAT queue as included in a cluster study. The analysis presented here indicates that the projects of any one of these substations are related to each other, but each of these substations and its projects are largely electrically independent.

It is worth reiterating that in the Vineyard power delivery system electrically valid groups of wholesale projects are not static. Much of the electrical interdependence and independence within the Vineyard system is established by the topology of the 70 kV transmission system shown in **Figure 4**. The 70 kV system is highly networked, and some changes to tie positions would essentially create different operational sub-networks and different project groups.

Network Impacts of Variable PV Output Might be Significantly Reduced by Avoiding Weak Interconnections

The impact on the power network of short-term, unpredictable variation in the output of large-scale PV generation, particularly under high penetration, is an ongoing topic of discussion.

Of the 137 different distribution and transmission project interconnections and variants New Power Technologies evaluated in simulation, and found 20 to have the potential to impact network voltage by 3 percent of nominal voltage or more due to variation in their output under the most vulnerable daytime minimum load conditions. However, 70 percent of these (14 of 20) are also in network locations New Power Technologies identified as weak—specifically, distribution feeder locations where New Power Technologies evaluated the voltage impact ratio at less than 6.0. Of the remaining six, four are substation interconnections (where New Power Technologies did not determine a voltage impact ratio) with quasi-voltage impacts that are still fairly small—between 3 and 4 percent of nominal.

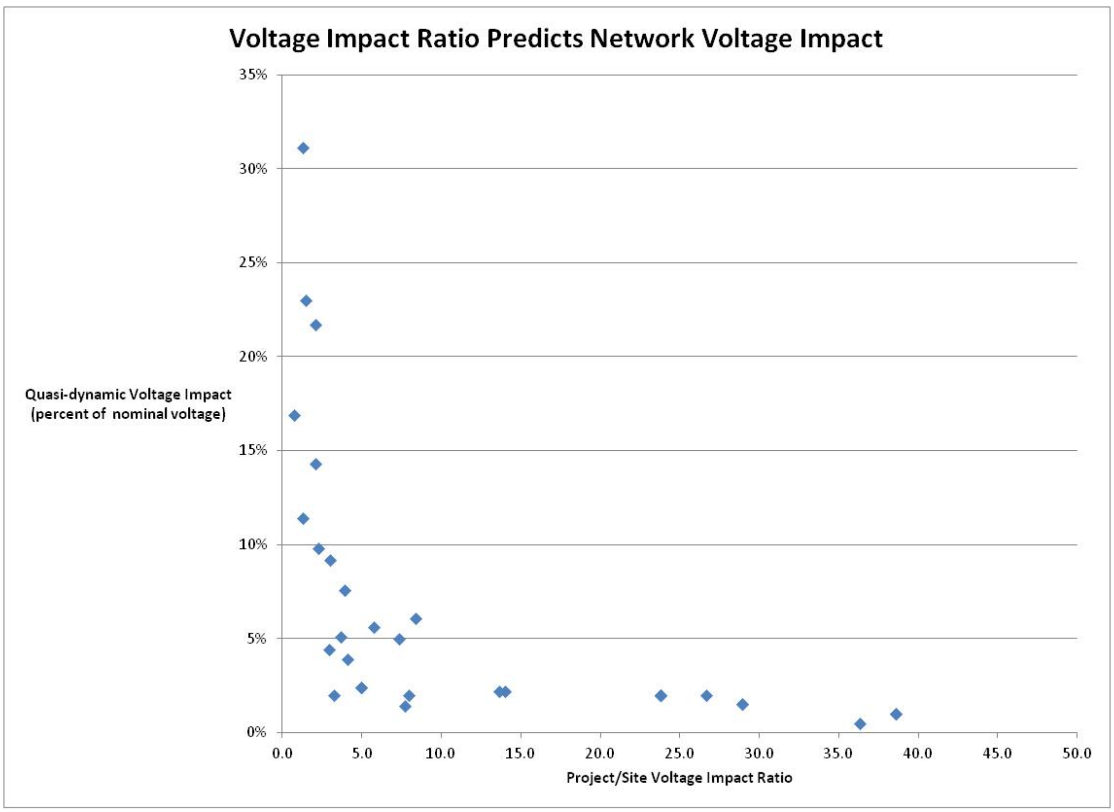
In other words, if the wholesale PV interconnections were restricted to strong locations within feeders or direct substation connections, for the majority of the projects the impact of their output variability on the power network would be very modest. Here, out of this group, only two projects—W23 and I73—would remain with the potential to significantly impact network voltage.

This also illustrates the risk in generalization and the value in project-by-project evaluation. In these results most interconnections do not have a significant network voltage impact. However, about 14 percent do, and 1.5 percent would pass through a demonstrably predictive screen. Any network impact evaluation method should effectively reveal these outliers.

Voltage Impact Ratio May be Valuable for Screening Weak Interconnections

These results suggest that voltage impact ratio is a useful indicator of interconnections that may have disproportionate impacts on network voltage. **Figure 42** is a scatter of the quasi-dynamic voltage impacts determined through simulation of the feeder-connected projects evaluated in this study plotted against the voltage impact ratio for each project at its point of interconnection (excluding projects with voltage impact ratios over 50). **Figure 42** clearly shows that projects with very large network voltage impacts always have very low voltage impact ratios. Voltage impact ratios around 5.0 appear to be influenced by other factors and the potential network voltage impact of projects with voltage impact ratios in that range must be evaluated more closely. Projects with voltage impact ratios greater than 10 evidently rarely have significant network voltage impacts.

Figure 42: Voltage Impact Ratio



Source: New Power Technologies.

In these results New Power Technologies presented system X/R alongside voltage impact ratio as an indicator of the potential for disproportionate system voltage impacts from a project. The Trepat feeder-connected Projects W9 and W10 presented in **Table 15** offer a good example of the limitations of system X/R if used alone. In each case the feeder sites have what seem to be very strong system X/R values. However, given the size of each project, the resulting voltage impact ratios are quite small, and the locations are in fact weak for those projects. This conclusion is confirmed in **Table 16** in the direct evaluation of the quasi-dynamic voltage impact of a 100 percent output change of each project, which in each case is greater than 7.5 percent of nominal voltage at the project site under minimum daytime load conditions.

At the same time, Projects W26 and W27 in Gamay Feeder 1105 provide an example where system X/R may be instructive. In **Table 10**, Project W27's site in Feeder 1105 has an apparently comforting voltage impact ratio of 5.8, where Project W26's voltage impact ratio of 3.7. However, in simulation, both projects have a fairly high quasi-dynamic voltage impact—both exceed 5 percent of nominal voltage—and Project W27 actually has a greater voltage impact than Project W26. This outcome for W27 is somewhat surprising given the project's voltage impact ratio but might be predictable given that the system X/R at the Project W27 site in Feeder 1105 is much lower than the system X/R for Project W26, as shown in **Table 10**.

It is also difficult to use the voltage impact ratio of an individual project to predict the voltage impact of that project as part of a group. For example, in the case of W14 and W13 under Bonarda substation, simulations showed that the individual voltage impact of each project at its point of interconnection is as great or greater than the combined voltage impact of the two projects at the substation. However, there are other examples where combined groups of projects had greater voltage impacts.

Ideally, even with a strong indication from either voltage impact ratio, system X/R or both, the voltage impact of a project, and especially a group of projects, would be confirmed via a simulation as was done for every project in this study.

Curtailability Might be More Important Than Voltage Management Features in Enabling Wholesale PV Development

As noted, the potential for wholesale PV at high penetrations to adversely influence power system voltage and/or cause voltage fluctuations due to their variable output is a topic receiving intense attention. In contrast, the results presented here provide numerous examples where high penetrations of wholesale PV have very little or no network voltage impact on either a steady-state or variable basis, but do cause or contribute to thermal overloads within the system, particularly under light load conditions.

The Hron sub-network and the Sangiovese and Grasa results provide just one example of instances with very high penetration of PV relative to load where equipment thermal limits are more limiting in practical terms than the voltage impacts of the projects. The projects under Gamay bank #3 provide another example where a group of wholesale PV projects causes reverse flow within the power system with no steady-state voltage violations or quasi-dynamic voltage concerns but an overload condition that is load-dependent.

Network voltage impacts from wholesale PV are more a function of weak interconnections than penetration. In the set of projects evaluated in this study New Power Technologies found relatively few truly weak interconnections. More importantly, though, these results show that through the use of metrics such as voltage impact ratio, system X/R, and by performing power flow simulations under different load conditions, weak interconnections are easily identified and as appropriate, may be avoided or mitigated.

This leaves the potential for thermal overloads within the network under some load conditions as a common impact or impediment to wholesale PV development. Active network management or active management of distributed generation output to compensate for grid constraints has been demonstrated as a way to incorporate additional renewable generation in a power system while avoiding grid upgrades.[26] Advanced inverter features to support real power output schedules or active management of real power output from an interconnecting generator are anticipated as possible I-DER functions in an update to California Public Utilities Commission (CPUC) Rule 21 now under development.[27] Both sources anticipate that managing wholesale PV project output in response to local load conditions to avoid thermal overloads would be most effective if implemented dynamically. This would add complexity through communication and control requirements, but would also achieve the greatest protection for the grid and the least curtailment of wholesale PV project output. These results suggest that the ability to curtail wholesale PV under different load conditions might more directly improve the network's ability to accommodate high penetrations of wholesale PV.

Networked Transmission May Increase the System's Capacity for Wholesale Generation

As noted, most of the Vineyard substations listed in **Table 1** are served from 70 kV transmission system that is highly networked, but configured as distinct operational sub-networks. This is shown in **Figure 4**.

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26 Bob Currie (Smarter Grid Solutions), et al; "Smart Commercial Arrangements for the Integration of Distributed Energy Resources (DER): Evidence from Europe and the United States", DistribuTECH 2014 Conference Proceedings, January 2014.

27 Energy Commission/CPUC; "Recommendations for Updating I-DER Technical Requirements in Rule 21," Version 6, October 2013.

The 70 kV network tie between Trepat and Hondarribi substations is one of several examples presented here where closing an open transmission network tie demonstrably relieves network overload and overvoltage conditions that otherwise result from the interconnection of certain wholesale PV projects. This suggests that the networked topology of the Vineyard 70 kV system might be used to increase the ability of the network to accommodate wholesale PV generation. In particular, when compared to reinforcing transmission lines, closing network ties may be a low-cost, low-regret alternative. Further consideration of this approach would require additional analyses beyond the scope of this study, including a review of the rationale behind the present topological configuration and an evaluation of the impacts on fault duty and the existing protection system.

Coordination of WDAT Queue and California ISO Queue Processes is Key

The wholesale projects identified for the Grasa substation provide an excellent example of projects from different interconnection processes and different queues affecting the same assets with compounding impacts. In this case, WDAT Project W30 and California ISO Project I9 individually show no overloads or voltage violations from their interconnection and appear to be feasible interconnections viewed separately. However, the results presented here show that they both impact the same 70 kV transmission line serving Grasa Substation. In fact, if the normal rating of that line is a constraint, Project W30 would preclude the interconnection of Project I9, and likewise Project I9 would preclude the interconnection of Project W30.

As another example, under the Bonarda substation the WDAT projects as a group and the California ISO projects as a group separately appear to use or exceed the capability of the 70 kV system serving Bonarda in terms of voltage and line loading. In other words, the existing 70 kV system might be able to accommodate the WDAT projects, but with no remaining capability for the California ISO projects, or vice-versa.

These are some of many examples of projects that would be evaluated under separate queue processes but that have similar impacts and affect the same power network assets. This underscores the value in continued coordination among these separate interconnection processes.

Acronyms

Acronym	Definition
California ISO	California Independent System Operator
DG	Distributed generation
CPUC	California Public Utilities Commission
DPA	Distribution Planning Area
Energy Commission	California Energy Commission
Hz	Hertz
kV	Kilovolt
Kw	Kilowatt
MVA	Megavolt amperes
MW	Megawatt
PG&E	Pacific Gas and Electric Company
PIER	Public Interest Energy Research
Potential DGD	Potential distributed generation deliverability
PV	Photovoltaic
TCUL	Tap changer under load
WA	Work Authorization
WDAT	Wholesale Distribution Access Tariff
WECC	Western Electricity Coordinating Council

APPENDIX A: Methodology for Evaluating High Penetration, Group, and Regional Wholesale PV Impacts

The following is a summary of the methodology that emerged as New Power Technologies performed this study. As stated in Chapter 2, there are regional network considerations that fell outside the scope of this study such as protection impacts and deliverability that are not included in this summary.

1. Develop a Purpose-Built Minimum Daytime Load Case

New Power Technologies continue to believe the most revealing operating conditions for evaluating the impacts of wholesale PV is a daytime period when loads are light and PV production is at its maximum, as in a spring weekend day. The case used for this study was somewhat contrived; the distribution portion was derived from a peak load case by reducing distribution loads, and the transmission portion was taken from a light load case which may have included elements more appropriate for true off-peak/night time conditions. Ideally planners would develop a case expressly reflective of daytime conditions, but with light loads to reveal the impacts of PV interconnections. Presumably such a case would be used alongside peak load cases and contingency cases as appropriate.

2. Perform a Systematic Evaluation of Individual Interconnections

Chapter 2 summarizes the factors considered in this study in evaluating individual feeder-connected wholesale PV projects:

- Potential feeder export
- Existing reclosing scheme
- Reverse flow at voltage regulation devices
- Existing circuit voltage regulation capability
- Steady-state voltage rise/voltage limit violation at point of interconnection
- Quasi-dynamic voltage impact of project output variation at point of interconnection
- Potential overload of upstream circuit components under loss-of-load conditions
- Relative power system weakness at the point of interconnection

Importantly, these factors capture differences in impacts due to different attributes of the network at different points within a given feeder. For individual substation-connected projects New Power Technologies did not perform a calculated assessment of relative weakness (but New Power Technologies did perform a voltage impact simulation for all projects). Note that penetration is not one of the factors directly addressed; though higher penetration increases the likelihood of feeder export or component overload which are addressed. Also, while reverse flow at a particular type of device might raise operational considerations to be addressed, feeder export seems to be more a point of information that a factor to be addressed.

3. Identify Groups of Projects That May Have Compounding Impacts or Affect Common Infrastructure

Obvious interconnection project groups include projects with a common interconnection point, projects on a common feeder and projects at or under a common distribution substation at the distribution voltage level. Beyond these groups identifying relevant groups becomes more difficult. These results show that physical proximity and administrative or institutional categorization of network elements or generation interconnections may or may not relate to their electrical interdependency. *After* interconnections are incorporated in an integrated distribution and transmission model and studied it is easy to see how portions of a network relate to each other, how far project impacts extend, and thus how project interconnections should be grouped.

4. Perform a Systematic Evaluation of Group Interconnection Impacts

For groups of interconnections at a common feeder interconnection point or within a common feeder New Power Technologies evaluated the group essentially the same as an individual feeder-connected project evaluation, usually including an assessment of the relative weakness of the group interconnection as if it were a single project.

This is a list of the factors that could be applied to other groups of interconnections that emerged during this study:

- Potential reverse flow through a substation transformer
- Potential reverse flow at the transmission level
- Potential overload of substation transformer or transmission line
- Steady state voltage rise/voltage limit violation at point of interconnection
- Quasi-dynamic voltage impact of group project simultaneous output variation

New Power Technologies performed the reverse flow and overload evaluations under daytime minimum load conditions rather than full loss of load as the loss of all load with all generation remaining on is an extraordinarily unlikely scenario. In many cases New Power Technologies repeated the reverse flow and overload evaluations under peak load conditions to see if the findings were intermittent or would persist under any load conditions.

Again, penetration is not one of the factors directly considered, though higher penetration increases the likelihood of reverse flow or overload. Also, while reverse flow at a substation transformer might raise operational considerations to be addressed, reverse flow in a transmission line seems to be more a point of information that a factor to be addressed.

It is worth noting that our evaluation of quasi-dynamic voltage impacts would be identical for a single project and for a group of projects at a single location, even though the group clearly has some additional diversity. Our approach would take into account locational diversity for a group of projects in different locations in the network, but again make no further allowance for the diversity of the group. Under conventional contingency analysis and reserve planning it arguably would be appropriate to consider instead the largest contingencies within the group rather than treating the group as a homogeneous whole.

The evaluation of group quasi-dynamic voltage impact also provides some indication of the stability risk the group represents. Some of the groups of interconnections evaluated in this study represent several *times* the locally served load. If the simultaneous loss of all of that generation has little voltage impact on a quasi-dynamic basis, it provides some assurance that such an event would not trigger a voltage collapse event.

This methodology is consistent with the conclusion supported by this study that variability of PV output is not a standalone concern, but becomes a concern where that variability demonstrably results in network voltage variation or other phenomena such as frequency variation or demands on reserves. Likewise it is consistent with the conclusion that high penetration of wholesale PV is not a standalone concern, but may demonstrably result in real concerns such as equipment overloads under light load conditions, steady-state voltage rise, or reverse flow at devices not designed for such service.

Accordingly, these individual and group grid impact evaluations identify several examples where large amounts of incremental generation can be accommodated without unacceptable voltage rise, with manageable voltage variability, and without overloading transmission or distribution lines (though substation transformers are commonly overloaded). At the transmission level, in many cases voltage rise appears confined to one or two substations, and flow impacts are often simply reversed direction in an already networked system.

Further, it is worth noting that some of the factors New Power Technologies evaluated proposed projects for evidently already occur in the Vineyard system. Existing wholesale generation exceeding local load and causing reverse flow, flow intermittently exceeding normal line ratings, voltage at more than 5 percent over nominal, and reverse flow in transmission substation transformers are all present in the light load base case before the addition of any of the proposed projects discussed in these results.[28]

This suggests that the Vineyard network has substantial capability to accommodate wholesale PV generation based on the individual project and project group evaluation method of this study, with grid impacts that are identifiable and in principle addressable.

28 The existing Aleatico Park solar projects reverse flow and overload the Aleatico-Gamay 70 kV lines in the minimum daytime load base case. Semillon 115/70 kV substation is shown in the minimum daytime load base case with reverse flow from 70 kV to 115 kV. Project W43, now in service, has the potential to overload Sangiovese substation at its stated queue capacity of 20 MW. Bonarda substation and Sangiovese substation are two of several substations with transmission voltage at more than 5 percent over nominal under minimum daytime load conditions in the base case.